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ISSUES IN NASA PROGRAM AND PROJECT MANAGEMENT

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edited by

Francis T. Hoban

Program Manager

NASA Program and Project Management
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The TDRSS Management Story

by Robert O. Aller
Former Associate Administrator, Office of Space Operations
NASA Headquarters

NASA initiated the Tracking and Data Relay Satellite System (TDRSS) Program in 1973 to acquire a new capability for tracking and data acquisition from NASA spacecraft in low Earth orbit through the use of data relay satellites in geosynchronous orbit. The data relay satellites would relay communications first between user spacecraft and an Earth station in the continental U.S., then to and from the NASA mission control and data processing centers. A principal objective was to provide the almost continuous coverage of low-orbiting spacecraft (including the Space Shuttle and Spacelab), which is possible from a geosynchronous orbit, contrasted with the limited visibility of low-orbiting spacecraft provided by the network of ground stations then in use. Equally important was the need to meet requirements for the very high data rates (50 to 250 megabytes per second) which were being projected for Spacelab and the free-flyer, Earth-observation satellites.

In the intervening years, the TDRSS program evolved to become, from a program management and contract management viewpoint, one of the most complex and challenging programs in the NASA experience. Problems began with the approach taken in initiating and implementing the program and with programmatic actions stemming from that approach. Other problems were caused by delays in Shuttle launch availability, especially the extensive delay after the Inertial Upper Stage (IUS) rocket failure in 1983 and the loss of Tracking and Data Relay Satellite-2 (TDRS-2) in the 1986 Challenger tragedy. Nonetheless, problems were overcome through dedicated efforts of both the government and industry team members, and today, TDRSS stands as a success story. The space-based tracking and data acquisition network envisioned in the early 1970s is now in place and is performing well. NASA has received more data through the TDRSS than through all ground tracking and data systems worldwide since the initiation of space activities. The support provided to date to the Space Shuttle and Spacelab and to free-flying spacecraft in Earth orbit has fully confirmed the operational concepts which led to the initial approval of the program.

In this article, I will review the management history of this program, revisit the contractual and management problems encountered, and present an assessment of the experiences gained, to identify "lessons learned" which may be of benefit to NASA in the planning and management of programs of this nature in the future.

The Program Start

As early as the late 1960s, NASA realized that the ground network, even on an expanded and upgraded basis, could not meet the technological needs of the relatively near future. Data rates were increasing beyond the capacity of the network equipment and, moreover, the necessary geographical dispersion of the stations had limited coverage of spacecraft data transmissions to about 15 percent of the orbit for most low Earth orbital spacecraft. It would have been possible to upgrade the ground station equipment to overcome the data rate deficiency partially, but it would have been very costly to do so, and geographic expansion of the system was impracticable if not impossible. NASA was already experiencing political problems with certain ground stations located in foreign countries. Even with augmentation, the need for almost continuous coverage could not be realized.

If, on the other hand, NASA could develop a tracking and data network system in geosynchronous orbit, high data rate transmissions could be received in real-time and relayed directly into a single ground station for about 85 percent of the time from all low Earth orbiting spacecraft, thereby permitting most of the ground-based network to be phased down. The circumstances themselves led to the only practicable decision that NASA could make -- an in-orbit tracking and data acquisition network. This approach was supported by a number of conceptual design studies, both in-house and contracted, to determine the feasibility of such a system. By the mid-1970s when it was necessary to make the final decision, it was felt that the required technology was already in hand.

The NASA budget environment was unusually constrained at that time. The costs of developing the Shuttle was devouring a major share of the budget to the extent that it was difficult to maintain a balanced space research and applications program. The TDRSS program was first proposed to the Administrator as a conventional NASA-developed and implemented system. However, the Administrator was reluctant to commit the up-front funding which would have been required for such a program, feeling that the constrained NASA budget resources should instead be reserved for the Shuttle development and other space research and development programs. TDRSS was viewed more as an operational support system, and there were precedents for obtaining such services from the private sector, such as the NASA Communications Network (NASCOM) for communications support of NASA flight missions.

The Procurement Phase

In this environment, and after much discussion within NASA and with Congressional committees, the decision was made to acquire the TDRSS capability from the private sector under a long-term service arrangement rather than to pursue a NASA-developed and owned system. It was also felt that savings to NASA could result if the contractors were permitted to propose a shared-service system containing separate commercial communications capacity along with the required NASA communications capabilities. In either scenario, the contractor was to design, finance, and build the system to meet NASA performance specifications, and operate the system and provide services to NASA over a 10-year period, with no payments to be made to the contractor until acceptable services actually began. All this on a fixed-price contract basis! Such an arrangement would allow the project to proceed on a timely basis, and NASA could defer inclusion of funds in its annual budget until it came time to pay for the services, presumably after Shuttle development had been completed. Special legislation would be required to allow NASA to incur a liability in the absence of appropriated funds and so avoid violation of the Anti-deficiency Act. With the concurrence of the Congress, NASA planned to enter into this off-budget financing arrangement, even though it was totally alien to its normal mode of doing business.

As it evolved, however, the prospective contractors were not able to provide the multimillion dollar funding for the project from their corporate resources nor to obtain financing from the usual financial institutions. (Remember, this was before the days of "junk bonds.") It had been assumed that a 10-year NASA contract would be adequate security, but the financial institutions would not provide loans without a "full faith and credit" backing from the U.S. Government. NASA itself did not have authority to enter into such an agreement; it would have required a statement from the Attorney General's office. However, at that time, an alternate financing arrangement was suggested to NASA by a representative of the Federal Financing Bank (FFB), a component of the U.S. Treasury Department. Under this arrangement, construction loans would be provided directly to the contractor by the FFB, with NASA assuming the role of guarantor of the loans. This had the advantage to NASA of a lower interest rate on the loans than would have been obtainable through the commercial institutions, even with "full faith and credit" backing.

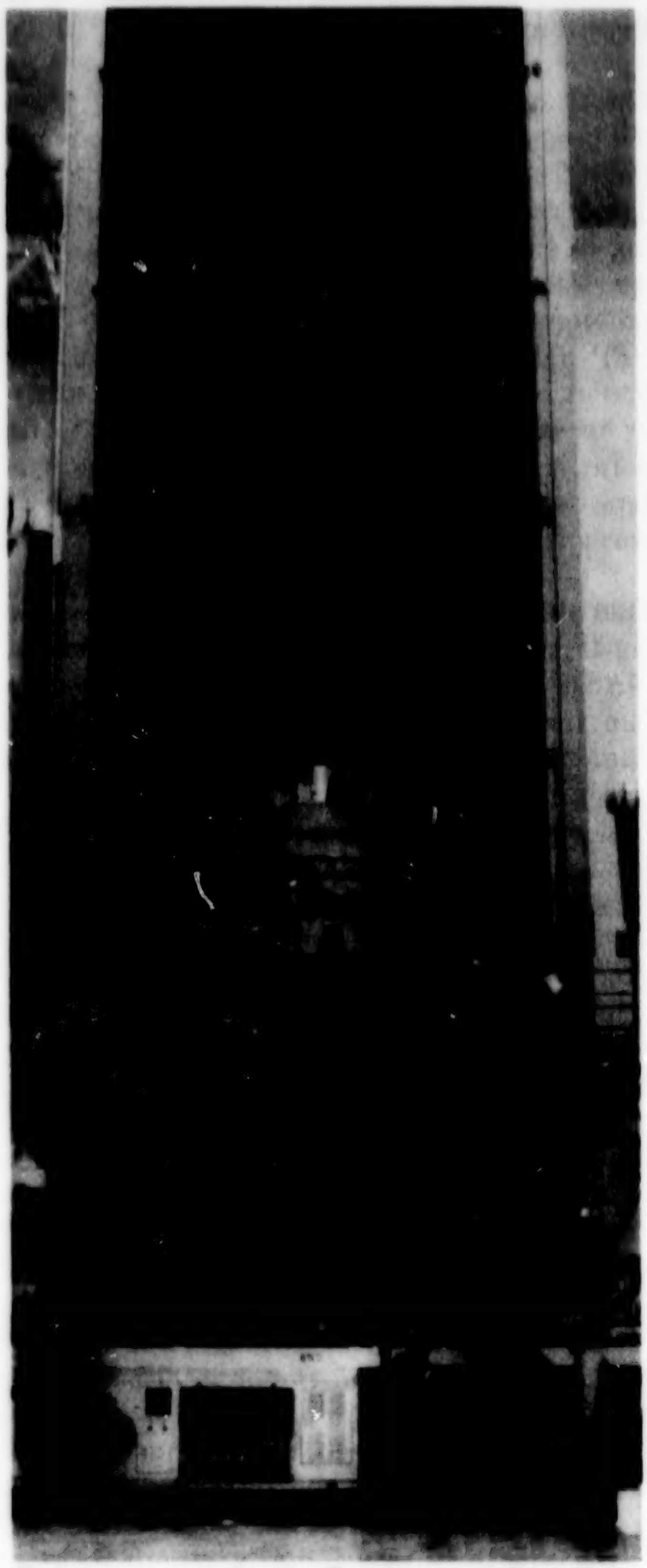
The Request for Proposal (RFP) entailed the development of a service and performance specification rather than a design specification. When services are acquired from the private sector, the performance parameters of an existing commercial system are already known. It then becomes a matter of determining if the commercial service will fulfill the government requirements. Here, however, it was necessary for NASA to specify in advance its own requirements as known or projected at the time for the planned 10-year service period, and really extending for 13 years ahead since it was expected that it would take about three years to design and build the system. As it turned out, some very important performance needs were not fully recognized at the time.

The RFP was issued in February 1975 for a two-phase procurement. After final proposals from two contractor teams were evaluated, the contract was awarded in December 1976 to Western Union Space Communications Company teamed with TRW and Harris Corporation, for development, implementation and operation of the TDRSS for 10 years of service to NASA. In addition, the space segment would have systems capabilities for Western Union's commercial satellite communication services, thus constituting a shared system in what was viewed as a joint venture with industry.

Problems and Their Solutions

The first major problems arose shortly after the project was under way. Potentially severe radio frequency interference, caused by high-power radio frequency energy bursts originating in eastern Europe, appeared to make full operation of the system questionable. The problem needed immediate correction. The RFP had specified performance criteria but had not cited the specifics of the radio frequency operating environment; NASA had, at this point, approved the contractor's proposed system design; and, most troublesome of all, it was a fixed-price contract.

Had this been the usual cost-plus-fixed-fee contract for a government-owned system, NASA would have been able to get involved in the immediate system redesign, issue a change order, and get the project moving with a minimum of loss of time and with some control over cost. In this "hands-off," leased-service mode, however, NASA was thrust into an engineering situation completely foreign to its culture. The project management office had been staffed at a minimal level considered appropriate for managing the service contract, but clearly not adequate for the in-depth technical design review and control of a conventional NASA space systems procurement. On the other side, Western Union, the prime contractor, with its orientation toward commercial communications services, had but little aerospace systems development experience or background; the subcontractor, TRW, had this experience and knowledge, but was not part of the NASA/contractor interface. Hindered by limited contractor access and precluded by the contract from giving technical direction, NASA became burdened with unseemly project delays and added expense. This was only the first of many circumstantial events that restricted NASA's ability to exercise technical management and control of the project.



Technicians transfer the Tracking and Data Relay Satellite and its Inertial Upper Stage, the primary cargo for STS-6, into the transport canister.

Other engineering changes, particularly in the ground station, resulted from new or changing operational requirements. Some of these came from the growing need for more stringent communications security provisions for the command and control systems. Usually, such changes to handle mission-unique requirements had to be made on the contractor's side of the system interface, a troublesome and usually costly process under a fixed-price contract.

The original contract contained provisions for penalties to the contractor for failure to meet specified levels of performance in the system. These were intended to promote a systems design with sufficient redundancy to assure reliable operations. However, the contract cost growth caused by engineering changes and repeated launch delays effectively eroded the penalty provisions to the point where the contractor would find it more cost-effective to skimp on redundancy and reliability and instead accept the risk of penalties for poor performance. In the ground station in particular, the contractor cut back significantly on the level of redundancy and even on the level of performance from the initial design proposal, contending that this system would still meet NASA's service specifications as given in the RFP. This type of situation led to many disagreements between NASA and the contractor, some of which had to be resolved by a change order and additional costs.

Since TDRSS was a leased-service type of procurement, it had not been subjected to the same type of end-to-end systems engineering analysis that would be normal in development of a NASA space mission support system, and the service and performance specifications expressed in the RFP did not bring forth a system design flexible enough to accommodate some of the changes in operational requirements.

ORIGINAL PAGE
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Another major problem arose from the interdependency of the TDRSS Project with other projects. The original schedule for launching the first three TDRS spacecraft was based on using the Atlas-Centaur, followed by the Shuttle/Spinning Solid Upper Stage-Atlas (SSUS-A) combination. The SSUS-A was never actually produced, and instead, the Air Force's IUS was selected for the upper stage launch. However, both the Shuttle and the IUS suffered numerous delays. During the same period, additional user requirements were placed on the TDRS by the Shuttle and other programs that necessitated major engineering changes to the TDRSS data system. The repeated lengthy delays inflicted severe damage on the potential for commercial service envisioned by Western Union, because service date plans for commercial service could no longer be met.

At the same time, serious conflicting viewpoints arose between NASA and Western Union over many issues associated with the shared system: cost allocations, impact of engineering changes on schedules, priorities of NASA requirements versus commercial requirements, etc. The net result was that Western Union and NASA reached agreement in late 1982 for NASA to acquire rights to the complete transponder system, including the commercial capacity, bringing the joint venture to an end. This agreement also changed the fixed-price arrangement of the operations phase to a cost-plus-award-fee contract that would allow much more flexibility for NASA. The development and implementation phase remained fixed-price.

By the time of the first launch in April 1983, the project was more than three years behind schedule. TDRS-1 was launched on the Shuttle with an IUS developed by the Air Force. The IUS rocket motors failed to burn properly, however, and injected the TDRS into an elliptical orbit rather than into the desired geostationary orbit. Ironically, the fact that the spacecraft had been designed for dual government/commercial service saved the day. Using fuel ordinarily reserved for commercial purposes, a team of government and contractor personnel devised a series of maneuvers effected with one-pound thrusters over the next several months which placed the spacecraft into its proper orbit. By December 31, the TDRSS was declared to have begun providing services. TDRS-1 has performed well since that date, and has been joined in orbit recently by two more TDR satellites to establish an operational system.

The 'Lessons Learned' Workshop

With the publication of the Reagan Administration Space Policy in 1988, a renewed emphasis was placed on the desire to commercialize to the greatest extent certain new space project undertakings. High-level discussions between NASA officials and Administration policy-level representatives confirmed the intent of the Administration to move aggressively toward this manner of operation. Internal discussions ensued at NASA, and we began a serious review of upcoming programs to see what might be done to respond to this new initiative.

One aspect of this review focused on the joint venture between Western Union and NASA, and on the leased-services approach to involve the commercial sector in such a joint venture. As a result, I felt that it would be useful to revisit the TDRSS experience to see what lessons might be learned that would assist us in dealing with the commercialization program. To that end, I called together about 30 present and former NASA and industry people who were closely involved in the development and execution of the TDRSS project, to review its successes and its problems, and to identify "lessons learned." The major findings of the group follow.

LESSONS LEARNED

Shared Service Concept. *The concept of combining a commercial need with an established NASA need is valid, and may offer significant savings to the government through shared costs; however, the rights and operational utilization needs, availability, and privileges of each party must be clearly established in advance.*

The proportions of cost for the shared TDRSS space segment was approximately 20 percent for Western Union and 80 percent for NASA. Under proper conditions, such an arrangement could benefit both parties. In this case, however, serious conflict of interest problems arose over many elements of the program -- design changes, launch vehicle selections, and delays in the launch dates. It was a situation where the parties had different motivations: NASA was concerned with assuring the most effective performance for NASA missions, while Western Union was driven by the necessity to profit from communications services. That this set of circumstances eventually led to dissolution of the "partnership" does not diminish the possibility of shared service, but does focus on the need for totally clear understanding from the beginning. The priority of the government's service requirements must be clearly set forth at the outset if that service is critical to a government mission operation.

Leased-Service Concept. *A leased-service concept should be based on the use of available commercial services or existing system technology if service is mission-critical.*

There was much more development required for the design and implementation of this program than had been apparent in the beginning due, in great measure, to the changes in requirements after the contract was in place. The TDRS services were critical to NASA's mission. With the realization that major changes were required, NASA reacted by attempting to influence the design to ensure viability of the program purpose. The service-level specification, however, did not permit NASA to specify a design change; only a change in service requirements could be initiated under the contract. A very serious deficiency of this arrangement was NASA's inability to provide to the contractor specific experience in spacecraft and ground systems design, experience that could have benefited reliability and performance issues.

Interdependency with Government-provided Services. *The interdependency of government-provided services to the establishment of a shared-lease service should be avoided or minimized to avoid government impact to the enabling of the leased services.*

The original contract specified that the first three TDR satellites would be launched on Atlas-Centaurs, which were, of course, fully developed operational launch vehicles. The next three TDR satellites would go on the Shuttle/SSUS-A, later changed to the Shuttle/IUS, all of which were still under development at the time of the contract.

However, early in the contract, the spacecraft design was outgrowing the Atlas-Centaur load capability. Spacecraft weight reductions could be made only by unacceptable reductions in redundancy and other reliability provisions, and it soon became necessary to shift the first three TDR satellites to the Shuttle/IUS. The subsequent Shuttle and upper stage vehicle development delays made it impossible to maintain the program schedule, impacting the Western Union commercial communications as well as services to NASA. In agreeing to provide launch services, NASA had, in effect, become a subcontractor to its own prime contractor for TDRSS services. This complex interrelationship complicated the lines of responsibility, placed NASA directly in line to the success of Western Union's efforts, and led to conflicts of interest in questions of launch delay, scheduling, etc.

Fixed-price Contract for Developmental Work. *A fixed-price contract is not appropriate for development of a mission-critical support system where significant technology development may be required or where substantial changes to requirements may occur.*

The nature of the fixed-price contract made close technical direction very difficult. The contract specified certain services that were to be provided; therefore, NASA could not readily control the systems design or make changes to it. Technical direction, as traditionally practiced by NASA, was not possible.

In addition, the project management structure was inappropriate for what became a developmental program. The prime contractor, Western Union, had little background in the aerospace technology necessary for a successful project. Their subcontractors were TRW for systems integration and Harris Corporation for the ground station; Harris was also separately a subcontractor to TRW to provide the spacecraft antennas. The formal NASA-contractor interface could not function in the normal manner. This eventually led to an informal interface between NASA engineers and those of TRW and Harris, simply in the interest of keeping the project moving.

Government Control under Leased Service. *Under a leased-service arrangement, NASA must accept some loss of control over physical assets and accept risks of system outages or failures.*

Effective control of the TDRSS assets was in the hands of Western Union as owner of the system. Under such an arrangement, the only way that NASA could influence the design of the system and, in effect, the quality of services was by specifying service requirements, including penalty clauses to the contract for failure of the contractor to provide the required services. In this particular case, the penalty clauses were not fully effective, due to inflation and NASA-induced technical changes. When the original basis for the penalty clauses no longer existed, the contractor was relatively free to take actions that might reduce the level of service without incurring undue monetary risk.

Operational Interface. *In a fixed-price environment, establish the government/contractor operational interface at a point where changes in requirements affect only the government side, so far as possible.*

In developing the Request for Proposal for TDRSS, the prime effort was to define service capabilities that would meet the requirements of future NASA missions in low Earth orbit. The system was planned to have a broad envelope of capabilities that would handle the projected needs of the users over the 10-year service period without major changes to the system. However, unanticipated changes in requirements began to emerge soon after the contract was in place. Efforts were made to confine the impact of such changes to the NASA side of the interface, and thereby not perturb the fixed-price service contract. However, as this was often not practicable, contract modifications then had to be made, particularly in the ground system, which had significant cost as well as schedule impacts.

End-to-end Engineering and Operations Analysis. *In a leased-service approach to obtaining a mission support capability, it is just as essential initially to establish a comprehensive end-to-end systems engineering analysis and an operations and testing plan as would be done in a conventional NASA space system development program.*

Probably because of the view of TDRSS as a service procurement, there was not enough attention given initially to a systems engineering approach for the total end-to-end system -- the Network Control Center, the Project Operations Control Centers, etc., as well as the TDRSS. Operational concepts that would have correlated the designs and the requirements of all portions of the overall system were not developed until late in the game. The result was unnecessarily complex interfaces among elements of the overall system which might have been avoided by utilizing a systems engineering approach from the beginning; in that way, operational concepts would have been defined at an early stage.

Considerations for Prime Contractor. *The prime contractor must be one who has an extensive background in the business at hand.*

When the RFP was issued calling for a long-term service, there appeared to be a perception in the aerospace and communications industries that a communications carrier was the proper type of company for the effort. The initial proposals received by NASA were in that structure. It is quite possible that the initial demands for capital to finance the project led some to believe that only huge communications-oriented companies would be able to fund such a venture. Regardless of the motivation, the prime contractor's limited exposure to aerospace systems technology was not sufficient for sound technical management of the contract. NASA is more accustomed to dealing with aerospace firms in terms of system and subsystem design. As the technical problems in the system grew, NASA often tended to bypass the prime contractor and work directly with the subs to resolve the technical problems. Thus, de facto decisions were frequently made that had not flowed through the appropriate management channels.

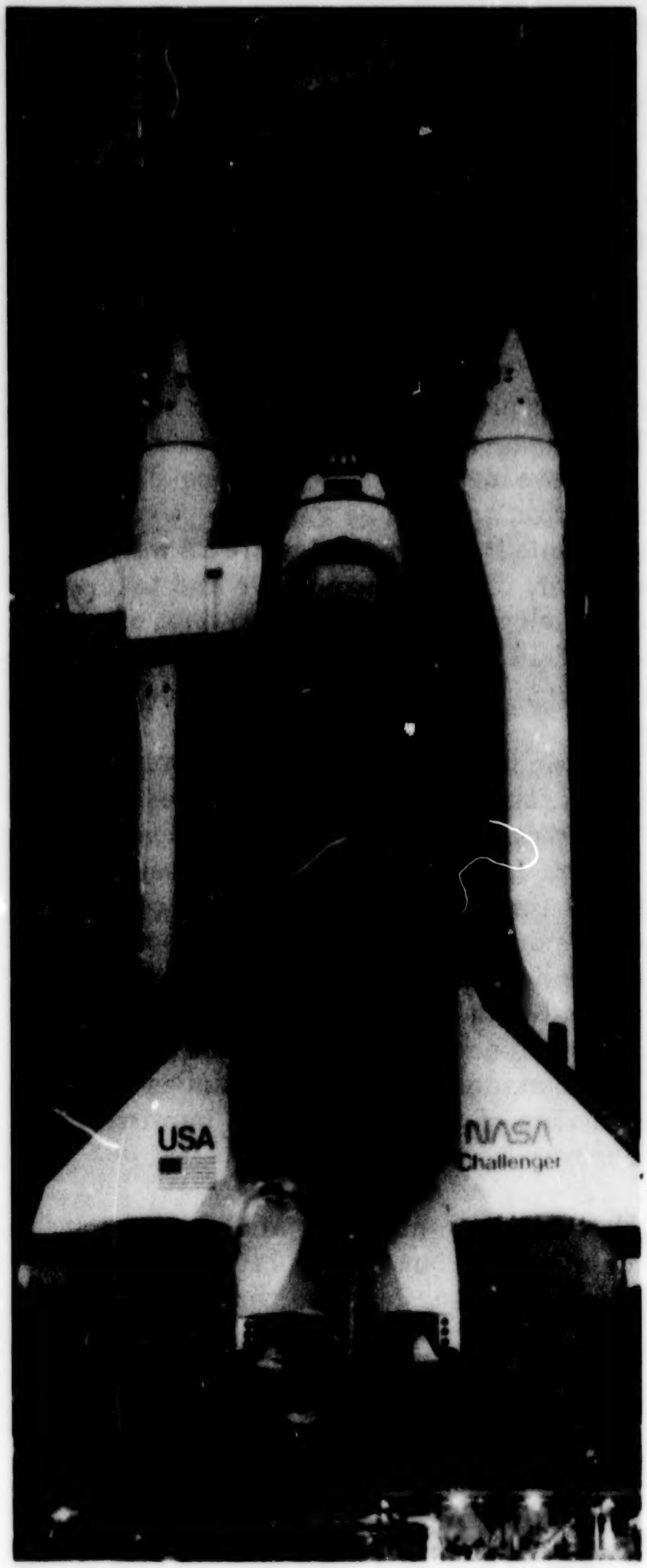
Conclusion

The TDRSS leased-service approach was designed to involve the commercial sector (i.e., a contractor) in developing and implementing a new mission support capability for NASA. This approach used contractor funding, with costs to be amortized and reimbursed to the contractor over a 10-year operations period. Thus, NASA budget requirements for this capability would be deferred until the service was actually provided. As it turned out, the Federal Financing Bank became the source of funding, with NASA guaranteeing the repayment to the Bank. This was to NASA's advantage since the loans were obtained at a considerably lower interest rate than would have been otherwise available to the private contractor. Budget requirements for the system were deferred from the start of the contract in January 1977 until repayment to the Bank began in late 1983. From a management point of view, this arrangement was not a problem for NASA to administer.

Unfortunately, this all took place during a period of high inflation and unprecedented rises in interest rates -- from 7.5% planned to a peak of nearly 16%. These effects, coupled with the repeated delays in Shuttle and IUS availability, caused serious cost growth; almost half of the present total systems cost is in interest charges. However, the cost of these interest charges now appearing as NASA direct costs would not have appeared in the NASA budget had the project been funded in the conventional manner. Instead, the interest costs would have been included in the Treasury budget as part of the cost of financing government borrowing.

The TDRSS will end its sixth year of service on December 31, 1989. Even with only one satellite in operation from December 1983 until late 1988, the service provided was far superior to that provided by the network of ground stations. With the launch of the third satellite in March 1989, the system is now considered operational, and will service NASA's data acquisition requirements into the early phase of Space Station Freedom. In 1991, a replacement satellite will be launched to replace the first satellite in the system. At this point, NASA has achieved what it set out to do -- install an in-orbit tracking data acquisition system providing 85 percent coverage for all low Earth-orbiting spacecraft, leading to the closing of all but a few ground stations.

We are now approaching the next generation of TDRSS operations -- an advanced TDRSS that will meet the requirements of future missions in the late 1990s and on into the next century. This undertaking attests to the validity of the operational concepts that began nearly 20 years ago. It has been a challenge to reach this point, and we must now use some of the "lessons learned" through this experience to help us cope with the problems that we are sure to face in the development of this next generation of space network systems, as well as other government procurements.



This double exposure by photographer Klaus Wilkins uses trick photography to cause the TRW Tracking Data and Relay System Satellite to appear to be inside the cargo bay of the orbiter Challenger at the Complex 39A launch site.

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Project Management and People

by William R. Marshall
Retired Manager, Shuttle Projects Office
Marshall Space Flight Center

These days a project manager can easily become so bogged down in the details and interruptions of scheduling, costs, and resolution of technical problems that it is easy to forget that people are an integral part of the total equation. One of the manager's primary responsibilities to employees is to motivate them.

Motivation is no easy task. A motivated employee works to get the job done; not just to earn a paycheck. The manager's responsibility is to create the conditions that will lead the employees to want to do their jobs.

A motivated employee, by definition, has a sense of pride and self-worth. The manager can help to instill these qualities in three basic ways: by setting an example, by demonstrating understanding, and by recognizing the employee's accomplishments.

Setting an Example

An effective manager leads by example. Enthusiasm about the projects undertaken, steady and effective work habits, and support of the employees in their efforts to support the project, lead to effective work.

A corollary of leading by example is informal communication. The manager must keep in touch with the employees. The manager should practice MBWA: Management By Wandering About. By spending time with the employees, informally, the manager will be aware of what they are doing and what their problems are *before* the problems become big. The manager will be available to them when they have ideas and new solutions to problems that arise, and will be more receptive to their input into the projects they are all working on together. This informal give and take gives the employees a sense of teamwork, of ownership of the projects, and reinforces their sense of pride and self-worth, or motivation.

The wandering about technique was applied by J.R. Thompson when he assumed the Center Director position at Marshall Space Flight Center. Immediately, employees began to respond throughout the Center organization with more informal communications which multiplied the data exchange between elements by an order of magnitude -- or more. This approach did not change the need for formal communication, but multiplied the total exchange of information and improved efficiency.

The manager must be careful, however, to maintain a balance in this system of informal communication. Management must continue to set an example and to exercise leadership, and to walk the fine line between informality and comradeship on one hand and formality and team effectiveness on the other. Should the manager make a mistake, the manager will be able to recognize it, admit it to the team, take full responsibility for it, and correct it. Should one of the team members make a mistake, it will be caught and rectified before it causes a disproportional problem.

Demonstrating Understanding

Thirty years ago, Douglas McGregor put forward two opposing theories of management, called Theory X and Theory Y. Theory X describes people as lazy and irresponsible, and professes that they need to be manipulated, controlled, and threatened in order for them to accomplish anything. They need a sense of order, control (from above), and security. Theory Y says that people have an innate sense of responsibility, that they naturally want to work and to work well, and that they do best when given challenges to their ingenuity and creativity. Actually, people tend to respond to the way they are treated. If their management expects them to be unmotivated and lazy and imposes restrictions to their freedom, then the employees are likely to become unmotivated and lazy. If, on the other hand, the manager demonstrates the expectation that the employees will be as dedicated and as motivated as management, they will be enthusiastic and proud to be working on the team.

Part of demonstrating understanding of employees is knowing their individual strengths and weaknesses, and knowing how to take advantage of the strengths. Ideally, the manager will be able to match each employee exactly to a specific job; if that is not possible, perhaps the job can be altered to fit the individual strengths and skills of the employee. The results of this understanding are more feeling of accomplishment on the part of the employee and smoother, more effective functioning of the team as a whole.

When new employees are hired, it is not always immediately apparent from their work history what their special skills are. The ideal solution to the problem of where to place them on the team is to offer a rotating series of assignments at first, with immediate assessment of performance in each. After that, the new hire can be placed in the most challenging and most effective slot.

All new employees at Marshall Space Flight Center are on a rotational assignment for one year. They are placed in three or more organizations during this time, and both management and they select a "best fit" at the end of this assignment. Many new hires do not return to the organization that interviewed and hired them, a sure indication that rotation throughout the organization may provide a better fit for employees and the organization.

To ensure that employees are successful contributors to the project, the program, and the organization, the manager is responsible for good, clear communication. The manager must make individual work assignments clear, show the employees how their activities contribute to the organization's goals, direct their activities insofar as necessary, and provide them with adequate tools and the proper environment for their jobs.

A good manager will take the risk of repositioning current employees to build the future of both the employees and the organization. The manager is responsible for the employees' success. Perpetuating the status quo of the organization, while it is comfortable, can lead to stagnation of both employees and organization. Taking the risk of moving people around is a sign of an innovative and progressive manager, and, done intelligently, results in increased productivity for the organization and greater job satisfaction for the employee. The manager who knows the employees and their individual capabilities will be able to do this intelligently and successfully. Often the manager can recognize employees' strengths and potential better than the employees do themselves.

After the Challenger accident, the manager of the Space Shuttle Main Engine research and development efforts was requested to assume responsibility for the Flight Engine operation.

This did not fit the manager's development background and was accepted only after considerable persuasion. Within 18 months, the manager had praise for his supervisor's judgment of his capabilities and appreciated the new assignment.

Recognizing Accomplishments

The usual way to recognize outstanding performance in the workplace is by promotion and increase in salary. In some instances, particularly at NASA, such rewards are not an option, because the employee has "topped out," or there is simply no slot available to advance into. In those cases, it becomes necessary to discover other ways to recognize an employee's accomplishments and provide the feeling of upward movement. NASA frequently does this with awards and special recognition. A manager can supplement this with additional, interesting assignments, or with organizational "perks."

Effective recognition is also personal. The day-to-day smile, pat on the back, encouraging word, or phone call to express appreciation for a job well done works wonders for an employee's morale. Say thank you. Of course, the employee is just doing the job, but the personal additional recognition aids in fueling ongoing motivation.

Recognition consists of both example and understanding, and is thus arguably the most important of the triad. Recognition is the manager's most powerful motivational tool. Management is ultimately responsible for the success of the project, the program, and the organization. Effective managers are effective leaders. Good managers grow through experience, education, and common sense.

NEWMAN'S LAWS

- **The length of the justification varies inversely to the dollars involved.** *Corollary: The significance of an item is inversely proportional to the number of words it takes to describe it.*
- **The more elaborate the cover the less accurate the contents.**
- **The probability of creative innovation varies inversely with the refinement of the procedures.**
- **You can't hold a staff meeting without a staff.** *Corollary: You can't supervise them if you can't find them.*
- **Newman's law of celestial mechanics: The last acceptable launch window for any given planetary mission is the one we are trying to get in the budget.**

-- E. Thomas Newman

Managing Projects -- An Industry View

by S.Z. Rubenstein
President, Advanced Systems Strategic Defense Center
Rockwell International

The project manager is the leader of a team of people charged with converting a broad set of mission objectives into an operating system. Project management is the set of principles and processes used by a team to manage a project from its birth to the end of its life cycle. These principles and processes encompass all the skills needed to plan, organize, direct, staff, and control the project. My comments in this article are based on nearly 30 years of experience in industry serving a variety of customers, including NASA, DoD, other government agencies and industrial and commercial end users. My examples are drawn from the Space Shuttle project.

Essential Concepts: Dynamic Process, Committed People, Communications

Today's manager must thoroughly grasp these three concepts -- have a working knowledge of them -- in order to successfully run a major project.

First, project management is a dynamic process. Managers operate in an environment where priorities shift and decision criteria change as a project progresses. Technology progress usually occurs differently than planned: funds are being expended, new people are coming aboard, and schedule commitment dates are coming closer. As a project gains momentum, it becomes harder and harder to shift direction and increasingly more important to make timely decisions.

Second, project success is achieved through the hard work of committed people. They are willing to overcome the hurdles, surprises, changes, problems, and heartbreaks that occur during project life. These people can be found at every level: on the factory floor, at the engineering workstation, in the schedule control office, at the shipping desk, in the launch Center, at mission control, in the controller's office, in the program office, within the congressional staff, and also within the executive offices. It takes committed people from all functions within all involved organizations to ensure that a project stays within performance, cost, and schedule commitments.

Third, communicating relevant information about the project -- upwards, sideways, and downwards -- is the cohesion that keeps the total team in a consistent direction. Information needs are different at each level of the project organization. Information needs at Headquarters to support a decision made by Congress on future funding are different than those of a Center project manager to support a decision on the allocation of resources among project elements. Still different are the needs of an industry line manager to support a decision on staffing for a six-month period, or a subcontract manager to allocate resources among companies. We often make the faulty assumption that all those involved in the project know what is going on. Communicating relevant information, either on project status or sharing a problem, is a principal mechanism for ensuring that the project will be successful.

However, before discussion of dynamic process, committed people, and communicating relevant information it is further necessary to understand two related subjects: quality and requirements.

Understanding Quality: An Attitude

Quality as a concept is often misunderstood. The contemporary definition is "meeting the requirements established for the system." For example, the functional requirements at the system level, specifications at the end-item level, the inspection process at the manufacturing level, and documentation at the test level are all requirements to be met.

Confusion often arises among the concepts of quality, safety and reliability, and product assurance. In both manned and unmanned space systems, stringent requirements are established for safety and reliability on the basis of the consequences of losing the payload or the launch vehicle. However, safety and reliability are similar to other performance requirements, although their priority in the requirements tree might be quite high. Similarly, a set of requirements is established for the processes needed to implement product assurance. Quality, in my view, is an attitude of commitment to perform to those requirements.

In systems design, development, and operations, requirements are established to ensure a system will do its intended job. Therefore, no compromise is made with respect to quality. If the system does not meet its requirements, then either it must be fixed or the requirement re-examined and changed to fit the behavior of the built system, if its intended job can still be performed. Although this might seem to be an extremely expensive way to operate, it is my experience that meeting the requirements or equivalently building a quality system is most cost-effective. The issue is making sure the requirements are correct; there are no options on quality. There is no substitute for producing a system that will do the intended job.

Understanding Requirements: The Foundation

When a project is initiated, the manager has three available resources: the mission objectives; the current state of the art technology (in its broadest sense -- tools, devices, standard specifications, and processes); and collective past experience. Very often, the mission objectives are a mixture of requirements and design. The state of the art of technology weaves its way into the requirements by the fact that many requirements are, in reality, point solutions rather than statements of the problem. Past experience is very valuable when properly used, but all too often we embed requirements that solve a problem no longer relevant to the one at hand. These distortions of true requirements can limit our ability to use technology advances creatively.

An essential task for the project management team is to ensure that requirements are precise and operationally valid and that sufficient time is allowed to iterate them in order to assure the simplest implementation. Requirements imposing unneeded constraints and unnecessary complication must be changed. In the ideal world, the "systems engineering process" should ensure that this task is completed before full-scale development begins. Since this does not always happen, it pays to scrub the requirements hard at the beginning, before trouble occurs, rather than wait for a crisis. I can guarantee that there will be many occasions to review the requirements during the life of the project.

LESSONS LEARNED FROM THE SHUTTLE PROGRAM

The Space Shuttle program was unique in that only a very few key personnel changes occurred from the start of development in 1972 until first flight in 1981. This was true for NASA, at Headquarters and the Centers, and for the prime contractors. Most projects, however, see a greater turnover during a development period as long as this. This particular group of people also had some unique shared experiences, having come through the Moon landing program and the Skylab program together. Many of the people were also involved in the earlier Phases A and B (conceptual and design) studies and had participated in a very large number of trade studies, from configuration to technology to ground support concepts.

My experience did not include the early programs or trades; and as I started on the Shuttle, I felt as if I were jumping aboard a racing train. As soon as I became involved in the decision-making process, it became apparent that external ground rules and constraints were changing, that resources needed to be shifted, and that many of the technology choices would have to be re-examined. The project stayed at this pace throughout the development cycle. Further, it was a resource-constrained program, constantly trading schedule for current dollars -- similar to many of today's programs. I will review some of the situations that occurred during the Shuttle development and extract some beneficial lessons.

Requirements and Early Design. During the early design phase, there is constant pressure to meet drawing release schedules; often mistakes can be made by releasing drawings before an adequate number of design iterations occurs. On the Shuttle project, experienced designers often withstood these pressures and ensured that their designs would meet performance requirements while staying within cost and schedule constraints. Sometimes -- due to pressure or inexperience -- they did not achieve this balance, for there is a fine line between being ready to release and embellishing the design.

The biggest payoff for reducing cost and improving operating characteristics occurs in the early design cycle. Current concepts, such as "Simultaneous Engineering" and "Total Quality Management," involve the total team (engineering, manufacturing, test, logistics, etc.) early in the design cycle. The objective of these concepts is to simplify the total production process, recognizing the value of design iterations.

The Space Shuttle Discovery final assembly and installation operations took place at Palmdale, CA.

The system implementation is reflected in a series of plans, i.e., engineering, software, procurement, quality assurance, manufacturing, etc. As iterations are made to improve performance, cost, and/or schedule, these plans must be kept in step. Early attention to long-lead items, critical processes, facilities tooling, and test needs will prevent future problems. These plans, when properly formulated, are the means to communicate direction to the project team and measure project progress. As a project manager, one must keep the pace moving quickly. One must always balance schedule pressure, the quality of the technical output, the implementation risk, and cost.

Mid-course Correction. The time span from preliminary design review (PDR) to critical design review (CDR) varies from project to project. It is a period of significant change: expenditures are increasing as prototypes and breadboards point to the need for technical changes. Often annual funding limits and other external events result in considerable schedule pressure, causing severe competition for funds among project elements. As project manager, one almost has to anticipate where

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the problems will arise and be prepared to make adjustments. Problems can take the form of schedule, dollar, design, or requirements changes.

During this period, there is time to change the implementation characteristics of the system. However, project managers should ensure that the data they are receiving are real (i.e., they must spend time visiting the development contractors -- within the company and at subcontractor and associate contractor sites). When these implementing organizations understand the need, the project manager will find that their ability to react to change is far better than either might think. Not making a decision to adjust can be far worse than a nonoptimal decision. Conversely, constant changes can result in chaos. It takes a seasoned team to make the right decisions and maintain configuration control.

The Build Cycle. In the ideal world, production fabrication occurs only after the design is thoroughly reviewed, all parts function as specified and are received on time, all software is received on time and perfectly matches the hardware, all subassembly qualifications are complete, all assembly and installation processes are perfect, and the expenditures of those functions that have finished their work are rapidly decreasing. In the real world, this rarely occurs.

Hopefully, the requirements cycle has produced good paper specifications and processes, and the quality attitude of meeting requirements is well established. If not, the project manager is operating on quicksand -- this is not the time to find out one has missed some critical mission objective. The responsiveness of the project management team is critical during this period. Resources almost always need balancing to meet the real rate of progress. The project rarely has adequate financial reserves to cover every problem, and manpower reserves to meet every contingency. However, at this time, the manager will also find that all the scheduled tasks do not have to be completed in exactly the sequence specified. There is considerable independent parallel activity off the critical path. With proper contingency planning, a responsive organization, and timely decision-making, performance requirements can still be met within cost and schedule commitments.

PERFORMANCE OUTSTANDING

Performance of the Space Shuttle's thermal protection system has exceeded expectations.

I well remember deciding to scrap a marginal lot of strain isolation pads (SIPs) used in bonding the thermal protective tiles to the Shuttle vehicle. During screening tests, it appeared that 1 to 3 percent of this lot was bad. There was enough SIP material to install at least 1,000 tiles, and this obviously would mean that 10 to 30 tiles might not have the proper strength. The post-installation tile acceptance tests would probably catch the bulk of the problem. However, manufacturing and material people developed a workaround plan that allowed us to wait for a new lot with minimal schedule impact to the total vehicle flow. We chose to wait. We updated our process specifications at the supplier and at our factory to eliminate the possibility of problem reoccurrence. We set the example to our floor personnel that we would accept no less than a quality product. And as a result, the thermal protection system on the orbiter has performed well, even better than expected.

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Qualification and Preparing for Flight. One of the least understood risks in project management is caused by lack of attention to the acceptance and qualification testing required to prepare for both flight testing and operations. Too often, proper resource allocation in this phase is neglected. (This means too little as well as too much.) Each of the technical disciplines seems to have its own criteria as to what needs to be proved by test versus how much can be proved by analysis. Cryogenic and hypergolic devices always seem to provide test surprises. For the Shuttle program, simulation of complete structural loads (including the thermal, vibroacoustic, and mechanical acceleration loads) was very difficult. Software and avionics integrated testing is always questioned relative to its completeness. (Are all the possible cases covered, including the fault conditions?) Testing to prove life limits can become very expensive, if not impractical. (Consider proving 10- or 30-year life with adequate margins.) The physical size of an end item and its operational modes (i.e., is it reusable, does it have asymmetrical orientations?) will determine whether environment test chambers can be used.

Six major steps a project leader can take to minimize such risks are: (1) include seasoned test personnel on the project team; (2) consider the test requirements early in the project life; (3) review the test requirements before testing begins (e.g., testing gaseous oxygen flow control valves, tile test panels, and structural and mechanical devices where the culprit was the test requirement, test fixture, or procedure rather than the device under test); (4) pay attention to ground and flight test results -- especially where actual performance diverges from predicted performance -- since these are potential trouble spots; (5) be prepared to make some tough decisions on the acceptability of test results versus redesign and retrofit versus limited life designation; and (6) not flying until problems that affect mission success have been resolved.

Shuttle ground vibration test operations took place at the Marshall Space Flight Center.

Operations. No matter how well one comes through the previous phases, the operational period will present some unique challenges. Flight results, technology evolution, turnaround improvements (if reusable), repair and wearout, new missions, the desire for increased performance, and the next version of the system will demand additional effort.

Frequently, those who authorize additional funds, be they Congress or Headquarters program personnel, are not prepared to continue investing during the program life. By this point, the project team should have some proven measures to judge the value of any change to the system. Too often changes are made without an operational set of priorities and the result is that systems degrade in performance rather than improve. The need for adequate technical development, maintenance of configuration data, and properly planned change points is as great now as at any other time.

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Any change will impact the full range of operational tasks, from test and checkout procedures to training. Careful screening of changes and implementation planning will keep the system operating successfully for many years. Interaction with the ground and flight teams will assure that valuable past lessons are not lost and that implementation proceeds smoothly. Not responding to valid needs for evolutionary change will shorten useful life and increase operating costs.

People: Building Commitment and Attitudes

Project success will depend on the commitment and attitudes of the people involved in the project. The leadership of the project manager and team is a dominant factor in establishing a motivational environment. Too often we focus on organizational structure rather than behavior. The organizational structure of a project can vary from a direct-line project team (everyone working for the project manager) to a highly matrixed organization. Which one is the best depends on many factors, such as the length of the project, the size, the skill mix, and the history of the parent organization. All need to be considered, while care is taken to balance project responsiveness and organizational needs.

When we had to replace a multiplexer on the Shuttle Columbia on the pad at KSC during countdown, the only available spare was in Palmdale, 3,000 miles away. Within 24 hours the spare was delivered, installed, and checked out in Columbia; the faulty unit was returned to the manufacturer; and the fault isolated to ensure we did not have a generic problem. Without the commitment of every person involved -- managers, technicians, logisticians, engineers, and pilots (at NASA, Rockwell, and the subcontractor) -- two or more days would have been lost, resulting in increased costs as well as some very unfavorable criticism.

Crew technicians complete a timely repair of STS-2.

Similar events happen every day in the life of a project. The approach the project manager and the team take has a great deal to do with instilling the commitment and attitudes necessary for success. The following are techniques I have seen others use and have used myself.

Building Teamwork. It is important to treat all people and organizational elements fairly. There is no substitute for ethical behavior and technical integrity. Open and honest communication among all team members is essential. Praise goes much further than blame; and criticism should be constructive, especially in large meetings. The manager and the rest of the team must work hard to establish a project outlook, a customer outlook, an end-user outlook, and a "can do" attitude. Getting these views accepted will obviate many organizational squabbles. It is extremely important also to build trust and teamwork among organizational entities: government, prime contractor, subcontractors, suppliers, Headquarters, and Centers.

Building Consensus. Since decisions are required at every level, effective interchange must take place with all involved parties. The manager listens carefully during the discussions and then works hard to get everyone to accept the decision as the agreed-upon course

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of action. Rarely are every person's desires met. While differences of opinion are acceptable, dissension is not. Furthermore, if new information becomes available, the issue must be revisited.

Quality is Mandatory. Since a quality product is the project's objective and requirements drive the entire system, all those involved know that their commitment to meet requirements will foster product excellence. Establishing the means to re-examine requirements, processes, and procedures will also foster product excellence. This applies to every aspect of the job: to letters and reports, as well as the hardware products. Everyone must understand the job to be done. In working to clean up processes and procedures, the project manager will do well to involve the doers as well as the writers. This will maintain an attitude of excellence and result in a quality product.

Time is of the Essence. Creating a sense of urgency is essential for project success. Schedules are established to ensure that all project tasks are synchronized and resources are properly applied. Since the manager's actions and team decisions are examples for everyone, they should be timely. Adequate time must be allocated and the schedule adhered to. The project manager must clearly expect schedules to be met or beaten and must follow up to make sure the proper resources are being applied. If difficulties arise, then searching for a workaround and eliminating the root cause is much more productive than looking for someone to blame.

Cost is a Driver. Cost is an essential element of the contract, and cost-effective performance is everybody's job. All organizational elements need to recognize and commit to the cost objectives. Getting quality and schedule performance are major factors in cost performance, and driving for simpler implementation improves both. The project manager has to ensure that enough time is allowed to get the simplifications at the design level and the participation of needed disciplines. Life costs must be a visible part of the decision-making process.

Keeping in Touch. Too often the project manager and team are consumed by meetings, requests for status, and myriad other duties which keep them in their own offices. This is an easy trap to fall into. But the project manager's presence is needed out on the floor, within the organization, at peer organizations, and at the contractors' sites. This presence will motivate the workforce, demonstrate concern, improve the information flow, and increase team responsiveness.

Selecting the Right Team. Since there is no substitute for talent, the project manager must select people who are technically strong (i.e., in engineering, manufacturing, scheduling, contracts, etc.) and who display the commitment expected. Often, rotation of the people into different assignments will help keep the talented people involved and committed to the project. Those who do not fit should be encouraged to find other tasks better suited to their talents. A strong team will create the peer pressure so vital to ensuring an effective attitude.

Reward and Recognition. There are many opportunities to reward performance. All too often in relations between the government, contractors, and subcontractors, profit is used as a negative incentive. If contractors meet their commitments, they have earned profit. If they have stayed responsive to overall project needs, they have earned a good share of the profit. If possible, unawarded period profits can be effectively rolled forward to provide additional incentives. Similarly, budget underruns can be used to initiate needed work earlier if project resources allow. Incentive and fixed-price contracts often allow sharing of cost savings that result in additional profits for the contractor while saving significant dollars for the government. Gainsharing is becoming a popular way of passing performance incentives to the individuals.

There are many ways to provide non-monetary incentives to a project team. Commendation letters, formal awards, public acknowledgment, and a simple, spoken "well done" will go a long way to building the commitment and attitude needed for project success.

Communicating Relevant Information

Some people believe that the answer to all our information needs is an infinitely large, automated data base with embedded expert systems to help us extract the information we need to make decisions. Others believe that all the key data can be put on three-by-five cards and carried by the project team through the life of the program. I would like to share a situation to help explain my view of what constitutes relevant information.

During the approach and landing test on the Shuttle program, the Rockwell team had responsibility for the vehicle prior to rollout from the hangar. We completed the prerollout tests, moved the vehicle out, and passed control to mission control at JSC. On one particular flight, we were having some difficulties with the inertial measurement unit's alignment. A decision had to be made as to whether the observed drift rates would be acceptable for flight. Although they were within specification and met all the criteria, there was obviously something going on that was different from our expectations. We had only a few minutes to decide whether we were "go" or "no-go" for that day. I met with the two responsible engineering managers and their recommendation was "go." The information that I needed was their technical rationale and how they conveyed the data. It was more than the numbers: it was also their confidence. Information needs are dependent on the problem at hand and the people involved. Information consists of more than computer-storable or written data.

Recognize Differing Needs. Each level in the customer, contractor, subcontractor, and user organization has different needs for information. Giving everybody everything is almost as bad as giving them nothing. Communications must, therefore, be planned in light of established performance milestones that measure progress meaningful to the level it is reported to, in a form useful to the receiver, and of value to those who provide it. Status data can be verified by frequent site visits.

In general, the two areas that are served the worst are the top of the program, where information is needed to plan future resource allocations, and the detail working level (including subcontractors), where daily work schedules are made. The top area needs to understand the future consequences of any major event, and the detail level needs to understand current detail status and decisions made that affect in-process work. Some effective communication techniques are discussed in the next sections.

Use Electronic Information. Modern computer-based systems offer tremendous capability to provide detailed information to a very large number of people. They can be used for detailed technical data (drawings, parts list, algorithms, system and software requirements, user notes, procedures, etc.). They can be used also for scheduling and control information (engineering orders, parts ordering,

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billing, inventory, configuration data, multilevel schedules, etc.) and coordinating information (electronic mail for bulletins, meetings, decision status, etc.).

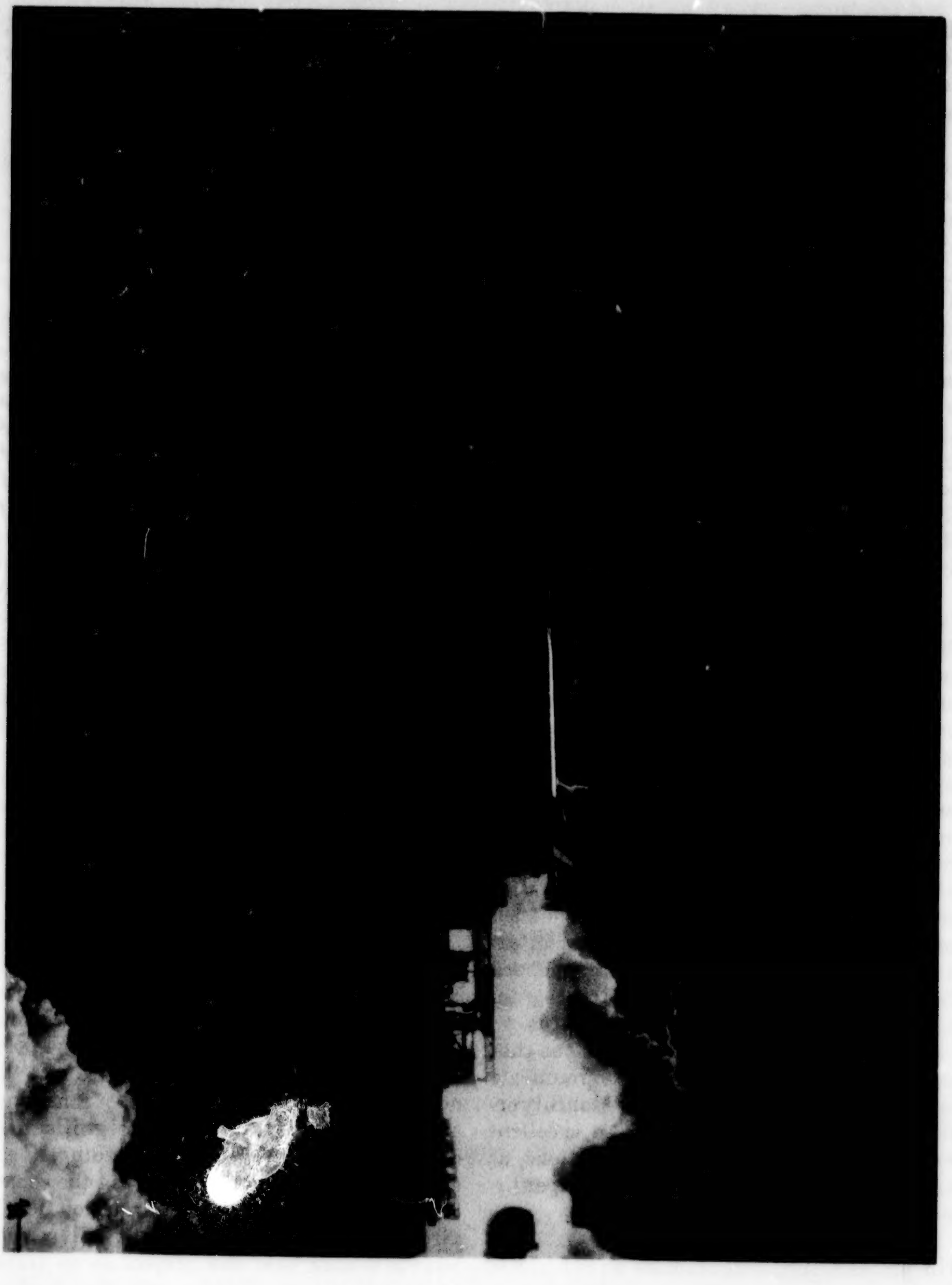
During Shuttle development, it would have been impossible to complete the program without computer-based information systems. However, difficulty occurred with multidiscipline information and multi-level (different user level) data. The fundamental problem is that data were not structured into logically consistent databases. Inordinate effort was required to translate, manipulate, and reformat information. Therefore, care should be taken on future projects to provide logical structures, standards, and user-friendly interfaces to ensure that electronic techniques are effectively used. (The NASA TMIS, Air Force UNIS, and many corporate information systems are working on this issue.)

Use Meetings to Communicate. During the Shuttle development program, many reviews, panels, and boards were scheduled on a regular basis. Used properly, these were effective means for communicating information, as well as for making decisions. Daily morning meetings between project functions at the contractor, between organizations at the launch site, and between subsystem project managers at the lead Center were used to measure the current pulse of the project and resolve issues that could impede work. Weekly meetings -- such as the avionics review board (ARB), technical status review (TSR), software control board (SCB), change control board (CCB), program review boards (PRBs), and vehicle status reviews -- were ways to facilitate decisions that had longer-term impact and to communicate results to affected parties rapidly. Monthly orbiter management reviews were an excellent means for synchronizing all the functions, as well as measuring cost and schedule performance.

The problem, of course, becomes one of how to do the work with all those meetings going on. With proper attention to meeting duration, participation, and completed staff work, these meetings are very effective. Letting the person who is closest to the issue present the information and the lowest-level person make the decision will speed up the process and spread the work. Written minutes, rapidly prepared, distributed, and posted for all to see will get the information to the "floor" where it is often needed the most.

Consider Contract Data as Important. Too often, the contract and its associated statement of work and schedule of deliverables are known only to a limited number of people in the project chain -- at the customer and at the contractor. Yet, the contract is the document that communicates the official requirements of the work to be done and the schedule for when it is to be done. Since government agencies rarely use the contract as a mechanism within their own organizations and the contractor operates similarly, there is a great misconception about the contract's value: maintaining its configuration, and using it as a mechanism to communicate and control work. Every project team leader should be familiar with the contents of the contract, for it will enable them to maintain a fair and equitable position on many issues that will arise during project performance. Insist on compliance with the contract and initiate contract changes when there is a legitimate addition, subtraction, or change to be made.

Communicate with Your Customer. The project team is both a supplier and a customer. It is very important that the team recognize this dual role. Too often I have seen the team consider its customers (customers are both the next level up in the project chain of command, and those organizations that significantly drive project requirements and funding) as enemies rather than friends. During the course of a long-term project, the information flow is virtually the only product that will assure your customer that the project is on track. Making this flow effective will also produce



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understanding of the external environment and its dynamics, which, in turn, will generate better decisions. An open, honest, and timely information flow among the project team, customers, and suppliers is a key ingredient of project success.

Conclusion

Project management, especially as it has developed through NASA's large-scale successes, is an extremely rewarding field. It enables each of us to take part and direct a portion of this nation's progress. In the project manager role, we take on considerable responsibility, for we are accountable for the use of very valuable assets. It is our job to ensure delivery of a system with the required performance, at or before the planned time, and within cost limits. Many skills are required and tools needed to be an effective project manager. Today, the task is being made both a little easier with improvements in communication media and simultaneously harder within our "fishbowl" environment. Building on past success and learning from mistakes are important.

I have discussed what I believe are some essential principles in effective project management. There is no compromise to quality; proper requirements are a solid foundation; things will change; committed people make the difference; and communication of relevant information will keep a team on course.

ACKNOWLEDGEMENTS AND COMMENT

I wish to thank C. Feltz; C. Kraft, Jr.; G. Merrick; J. Peller; and P. Wilkinson for their review and constructive criticism of this paper. I also wish to acknowledge the contribution of Tom Kennedy and his editorial staff. It is difficult to provide adequate coverage of each item in this article. For example, establishing a "can do" attitude, as noted in the section on teamwork, could be a paper in itself. In this light, there are many other items that are worth treating in project management. They include pre-project authorization, subcontract management, check and balance, software management, end-user involvement, man-machine interaction, systems engineering, configuration control, hardware-software integration, performance measurement, and resource management. These subjects should be included in any project management discussion.

Project and Systems Management in the Apollo Program

by Dr. Eberhard Rees

Former Director of Marshall Space Flight Center

(adapted from a talk given at The World Management Congress in Munich, 1972)

Basically, project and systems management is nothing new. It is axiomatic that since the dawn of history there have been groups of human beings trying to achieve a common goal within a certain time span and with available resources. These project-oriented groups were immediately confronted with the problems of organizing and managing such efforts and resources in order to reach their goal on time and with minimum expenditure. In modern times we call the educational approach to such an undertaking "Project and Systems Management." Large projects of a scientific and technical nature generally involve:

- **A multitude of government agencies, industrial firms and other organizations, sometimes on an international basis;**
- **Funds in the multimillion to billion dollar category;**
- **Complex technology sometimes reaching beyond the state of the art;**
- **Large forces of scientists, engineers, technicians and administrative personnel; and**
- **Construction of extensive and highly specialized facilities.**

This type of project became more and more common in this century and especially in recent decades to solve problems of national and worldwide importance, to pursue large-scale scientific endeavors, to meet the needs created by a rapidly expanding world population, or to achieve other goals. It soon became evident that such projects, of great magnitude and complexity, had to be considered under the overall "systems" point of view continuously during execution. The alternative to such a concept leads inevitably to non-optimal technical solutions, cost overruns, and schedule slippages which would occur to the embarrassment of the responsible country, agency or firm. Therefore, terms like "Systems Management," "Systems Engineering," "Systems Planning," etc., were introduced to describe the systems aspects that had been emphasized as an inescapable necessity.

The management scheme that was developed and applied to the Apollo Program, a complex and technologically difficult program, is particularly interesting. It is now well-known that the technical complexities and the pioneering nature of this unprecedented undertaking were finally very successful, but the program was also accompanied by shortcomings, setbacks, and deficiencies during its execution -- all of which challenged the management system. It soon became clear that the project management had to be extremely flexible and capable of meeting unforeseen demands. It was also apparent that determination, resoluteness and faith would be vital if the goal were to be achieved.

To assure success of the Apollo Program, the first order of business was to minimize technical risks or actually mission risks as much as possible and, at the same time, to keep closely to the time schedule. Because of the rigid de-

mands of this time schedule, it was necessary wherever possible to engage in parallel rather than consecutive developments. In order to reduce technical risks, backup solutions in certain unprecedented areas, sometimes down to the component level, had to be concurrently pursued. For example, all possible abort schemes one could think of were considered and designed for, to provide the maximum possible safety. This concept is expensive, but it was accepted as an alternative to increased possibility of failure of the whole program.

Tight budget control and highest economy in expenditure were, of course, strong requirements but were subordinate to technical needs and the demands of the time schedule. Naturally, there is a trade-off between acceptable technical risks or product quality, time schedule and project cost. For instance, to eliminate the technical risk problem, frequently undue quality control or overtesting of hardware is applied which delays schedules and makes costs skyrocket. If the program management permits faulty components to enter the system -- due to lack of quality control and testing -- the components would only be detected in overall checkouts. And finally, unrealistically short time schedules endanger the quality of the product and cost control, whereas long, drawn-out time plans increase total project cost.

In summary, there has to be an optimum balance among technical performance, time schedule and cost. In the Apollo Program, this balance was deliberately shifted toward technical performance and time schedule. Depending on the nature of a project, such a balance could as well shift in the direction of economy and trade-in on technical performance.

Short Summary of the Apollo Program

For a better understanding of the management concept and of the problems confronting management, a brief history of the Apollo Program might be helpful. The mission as stated by the President of the United States and approved by the Congress was to land a man on the Moon in the decade of the 1960s and return him safely to Earth. During the excursion, scientific experiments were to be conducted for exploration of the Moon and its origin in order to provide a better understanding of the possible age and creation of the solar system. Also, other corollary research was to be undertaken.

It has been common practice in government circles to use the term "program" to describe a large, multimillion dollar undertaking. Within such a program, major elements have commonly been referred to as "projects." Thus, the lunar program in its entirety is referred to as "Apollo." The Saturn launch vehicle, an element of the total program, would properly be called a project. It is my understanding that in commercial or industrial practice, the term "project" is generally used rather than "program." For consistency, I shall use the term "program" for Apollo.

The program was started in 1961. Early snapshot estimates of cost were between $20 billion and $40 billion. After the program was laid out and firmly established, detailed calculations brought the estimates closer to $20 billion. Of this money, approximately 90 percent was spent in industry and 10 percent in government operations. During the peak of the effort, approximately 12,000 government employees and approximately 300,000 people in industry were employed. An investment of approximately $2.5 billion in new construction of facilities was made all over the United States at industry and government installations. These included the build-up of new government Centers; namely, the Manned Spacecraft Center at Houston, Texas, and the Kennedy Space Center at Cape Canaveral, Florida. It also comprised an expansion of the Marshall Space Flight Center at Huntsville, Alabama, including subsidiaries for production and testing at other locations.

The total program consisted of the development and production of three types of launch vehicles; namely, Saturn, Saturn IB and Saturn V, and two types of spacecraft: a Command Service Module and a Lunar Landing Module. As a precursor, the Gemini Program was introduced. The special objectives were to improve life support systems and to develop docking processes, extravehicular activities and other techniques for Apollo.

Basic Principles Established in the Apollo Program Management System

After agreement had been reached on the method for traveling to the Moon and landing, and departure from the lunar surface for return to Earth, attention was turned toward establishing certain management basics to assure effective program execution. The size and complexity of the effort added an increased importance to such considerations.

First of all, there had to be "a superior planning effort." I venture to state that, without diligent planning -- especially systems planning -- right from the start, any project is doomed sooner or later to run into most serious difficulties. To recover from such planning failure costs large sums of money and time delays. It also brings a program into technical trouble which, as history has shown, could result even in cancellation.

Solid planning starts with master plans on hardware, software, and overall systems as to technical approaches; resources such as facilities, manpower and funds; and, finally, schedules. Important are detailed breakdowns of the overall job and the system into subsystems and what is called in Apollo "work packages." Then come the significant areas of planning of contracts and the contractor structure. This results in the determination of which packages to assign to prime contractors and, in special cases, to major subcontractors who are to be selected by Source Evaluation Boards. This selection is based on work statements, Requests for Proposals, and their submissions. The selected prime contractors have to be incorporated immediately into the planning activity.

It is strange that so few otherwise gifted managers and engineers do not see the significance and the great importance of proper planning. Such seems to be the case, however. It explains at least partially why we had great difficulties in finding technical experts who understood the value of planning. For the military, strategic planning is a matter of course. The same is true for any commercial undertaking where to neglect planning is to court bankruptcy. Why it is so hard to introduce proper planning into project and system management of projects of a more scientific nature is perplexing to me.

For success in any program or project, large or small, I consider it a dominant principle that management must have what we in the Apollo Program called "visibility." This means that the management at all levels should know almost in "real time" what is going on in the program: technical occurrences, schedule progress or delays, and financial status. From the outset of the program, proper and effective channels and ways of communication have to be established on the government side between upper and lower echelons of management. Similarly, the prime contractors must provide equally effective channels down to their respective subcontractors. Such an information system should not only depict the past and present status, but, more importantly, should also enable management -- again on all levels -- to predict trends in the progression of the program. The prediction of trends for some months ahead, or even longer, is vital for taking corrective steps before the program runs into impediments. The capability of management to foretell trouble and thus avoid it by appropriate actions was one of the major cornerstones of the Apollo success.

Next of importance was the establishment of certain "review milestones," that is, scheduled dates of management review between government and prime contractors. Such reviews are, for instance, in a chronological sequence:

Program Requirements Review	PRR
Preliminary Design Review	PDR
Critical Design Review	CDR
Design Certification Review	DCR
Pre-Delivery Turn-Over Review	PDTR
Flight Readiness Review	FRR
Countdown Demonstration Test and its review	CDDT

Figure 1 shows these reviews over the life of a program and the process applied to lead to a particular launching. Some indication of timing of the review span may be gained by noting that the Countdown Demonstration Test and review preceded an Apollo launching by five weeks.

In the Apollo Program there were many more reviews beyond those shown. They all served to critically examine and assess the project status, to affirm the quality of the product and its reliability, and to assure systems safety. Every review resulted in protocolled action items. As the resolution of problems raised at each of the reviews was completed, the contractor was authorized to go ahead with the next increment of the overall plan.

Also employed as an important management tool was the PERT, or Program Evaluation and Review Technique. This well-known approach needs no further elaboration.

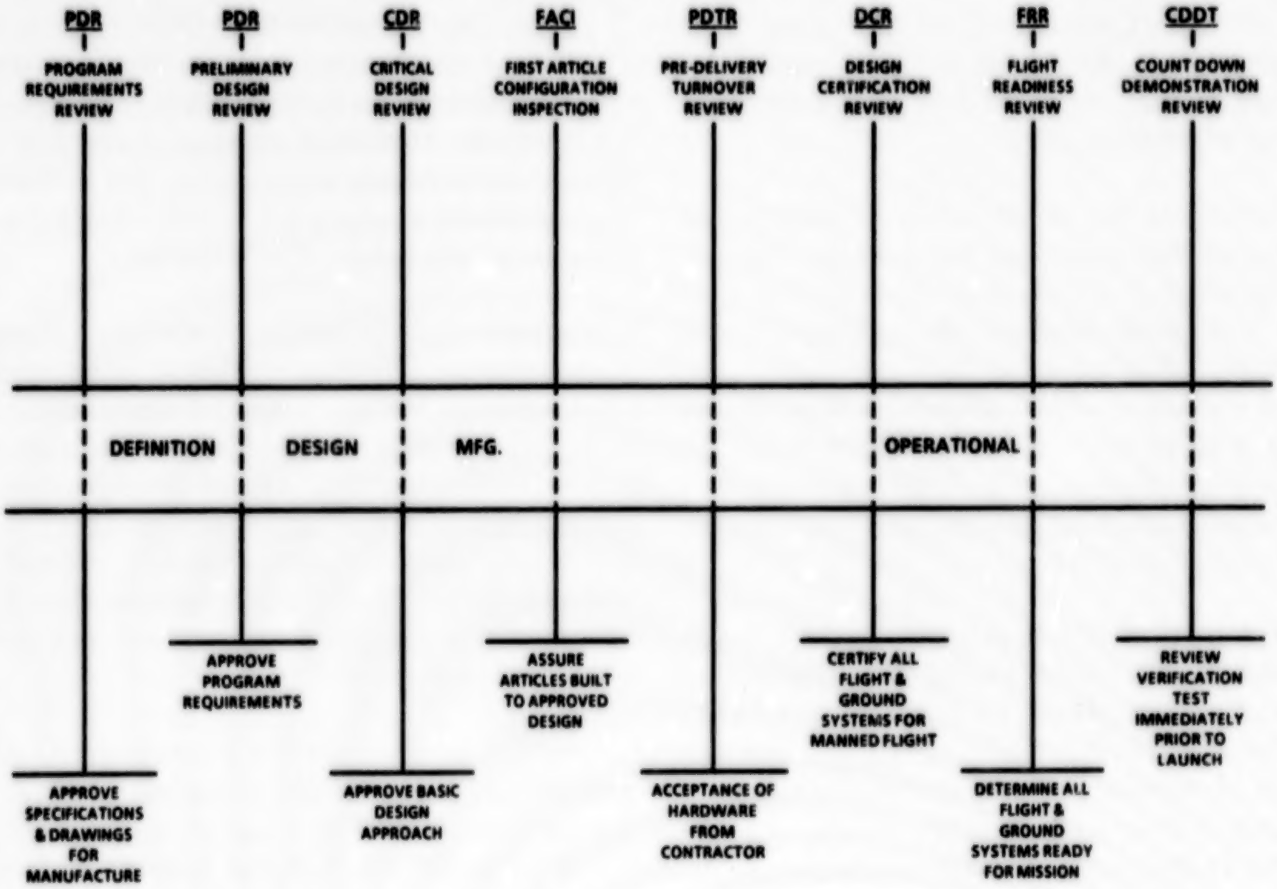

PDR
PROGRAM REQUIREMENTS REVIEW
PDR
PRELIMINARY DESIGN REVIEW
CDR
CRITICAL DESIGN REVIEW
FACI
FIRST ARTICLE CONFIGURATION INSPECTION
PDTR
PRE-DELIVERY TURNOVER REVIEW
DCR
DESIGN CERTIFICATION REVIEW
FRR
FLIGHT READINESS REVIEW
CDDT
COUNT DOWN DEMONSTRATION REVIEW
DEFINITION
DESIGN
MFG.
OPERATIONAL
APPROVE SPECIFICATIONS & DRAWINGS FOR MANUFACTURE
APPROVE PROGRAM REQUIREMENTS
APPROVE BASIC DESIGN APPROACH
ASSURE ARTICLES BUILT TO APPROVED DESIGN
ACCEPTANCE OF HARDWARE FROM CONTRACTOR
CERTIFY ALL FLIGHT & GROUND SYSTEMS FOR MANNED FLIGHT
DETERMINE ALL FLIGHT & GROUND SYSTEMS READY FOR MISSION
REVIEW VERIFICATION TEST IMMEDIATELY PRIOR TO LAUNCH

Figure 1. The Apollo Review Process.

Configuration control was another necessary management tool in the Apollo Program. This control scheme assured that:

- The contractor followed acceptable drawing room practice as to procedure and discipline;
- Design intentions were carried through manufacturing;
- Only mandatory changes were approved;
- The exact configuration, known down to the most minute detail, was delivered to the launching site; and
- Failures or unsuitable hardware or material could be traced down to the point of origin. Apollo management called this "traceability."

Configuration control carried out in a strict sense is very expensive. It is, therefore, vital that these controls not be overdone and that they are wisely introduced to prime contractors and subcontractors.

Application of the penetration principle did not stop at the government-contractor boundary. Instead, it permeated through the contractor organization to the subcontractor structure. Spawned by this approach, improved failure analysis appeared throughout the system; in-process inspection was maintained at a high level; and receiving inspection techniques and effectiveness were improved, among other benefits.

The application of the penetration approach resulted in a a vastly improved and effective communication channel with a host of side benefits. So while it might on the surface appear as an invasion of prerogative by the government, actually penetration should be looked upon as the close interaction of highly dedicated, competent technical and scientific personnel, all motivated by the impressive challenge of a huge complex program, no matter whether they are government or contractor employees. Most instrumental in this government-contractor relationship was the establishment of resident personnel in the prime contractor plants.

Another point basic to the management of the programs involves "contracting principles." Early in the Apollo Program, cost-plus-fixed-fee contracts were employed. The reason for using this contracting approach is rooted in the uncertainties of effective, close pricing in such a program with its many unknowns. Subsequently, the incentive fee contract was introduced. Essentially the fee applied consisted of two parts, one a base fee of modest proportions and the second a scaled or incentive segment. As the name implies, the amount of incentive fee awarded to a contractor in addition to the base fee was a direct result of success in meeting program product requirements for performance, cost, and time schedule. The incentive fee contract lends itself well to hardware contracts with reasonable, well-determined milestones, cost levels and schedule. (I should point out here that in several cases where contractors were experiencing troubles, effective management practice was considered in adjudging fee.)

In contract arrangements where the parameters are not easily distinguished in advance, a variation known as award fee contracting is used. The contractor is adjudged on a more general basis; support service or engineering service contracts fall into this category. It may be seen rather clearly that this method of contracting is motivational in nature, thus fulfilling an important management requirement cited earlier.

Beyond the contracting device, additional and continuing motivational or inspirational techniques were used. While the award and incentive fee channel reached the interior of an organization through conventional management channels, there were others that appealed directly to the workforce of contractor and subcontractor. Located in the program and major project offices was a Manned Flight Awareness Office. The function of this office was to keep all program workers aware of the need for success by each individual. This was an effective technique that became tangible when merit awards and recognition were issued.

There are a number of other pertinent principles upon which the effectiveness of program management depends. Although they apply in other management schemes and in programs where the government is not involved, in a program-oriented structure, they are critical:

- Organize and motivate to achieve effective high morale in the workforce;
- Delegate authority clearly, concisely and positively to achieve timely decisions;
- Apply innovative concepts and techniques courageously;
- Keep objectives pointed toward the goal;
- Require continuing study and application of the systems engineering approach; and
- Relate actions to schedule and to budget continuously.

The Apollo Management System

In the actual managerial arrangement that used the principles I have mentioned to manage the program throughout its life, we did not enjoy any measure of managerial "genius" in running our changing, dynamic organization. On the contrary, our management system evolved after some painful experiences in the early days of Apollo. In fact, at the beginning of the program in 1961, there was no common system in existence within the rather young National Aeronautics and Space Administration. Then as the program gathered headway and matured, the management system became better defined, changing as necessary to keep pace with unfolding events. Early it was learned that in the environment of a big development project, there can be no static system. Change and evolution are inevitable.

Figure 2 is what we called the "Apollo Program Trend Chart." Management used this chart to follow the progress of every major component such as rocket stages, engines, spacecraft, etc. In this case it was employed as a master chart for predicting the landing date on the Moon. On the ordinate you see the planned launch date and on the abscissa the reporting date or the status. This visibility scheme was introduced in 1965 after the first lunar landing date, originally planned for the first half of 1967, slipped several times.

By 1962, after the decision on how to go to the Moon and after the introduction of the Gemini Project, the Apollo Program began to take shape rapidly. Budgets had increased decisively. American aerospace industries and universities were significantly expanding their involvement. Also, of course, by this time three sizable Centers were involved to capacity in the technical and managerial demands of their respective Apollo assignments. This involved multimillion dollar projects at each -- the command module, service module and lunar module at Houston; three stages and an instrument unit at the Marshall Space Flight Center in Huntsville; and assembly and launch operations at Cape Kennedy. Coupled with the national involvement of the industrial complex, the need for innovative overall management was clear. For this and other reasons, the Apollo Program management office in Washington, and the project management offices at the three field Centers, were thus restructured and strengthened to fulfill the vital role of the overall integration and management of all contractor, field Center and university efforts.

Figure 3 shows how the Apollo Program Office was placed in the complex of the Manned

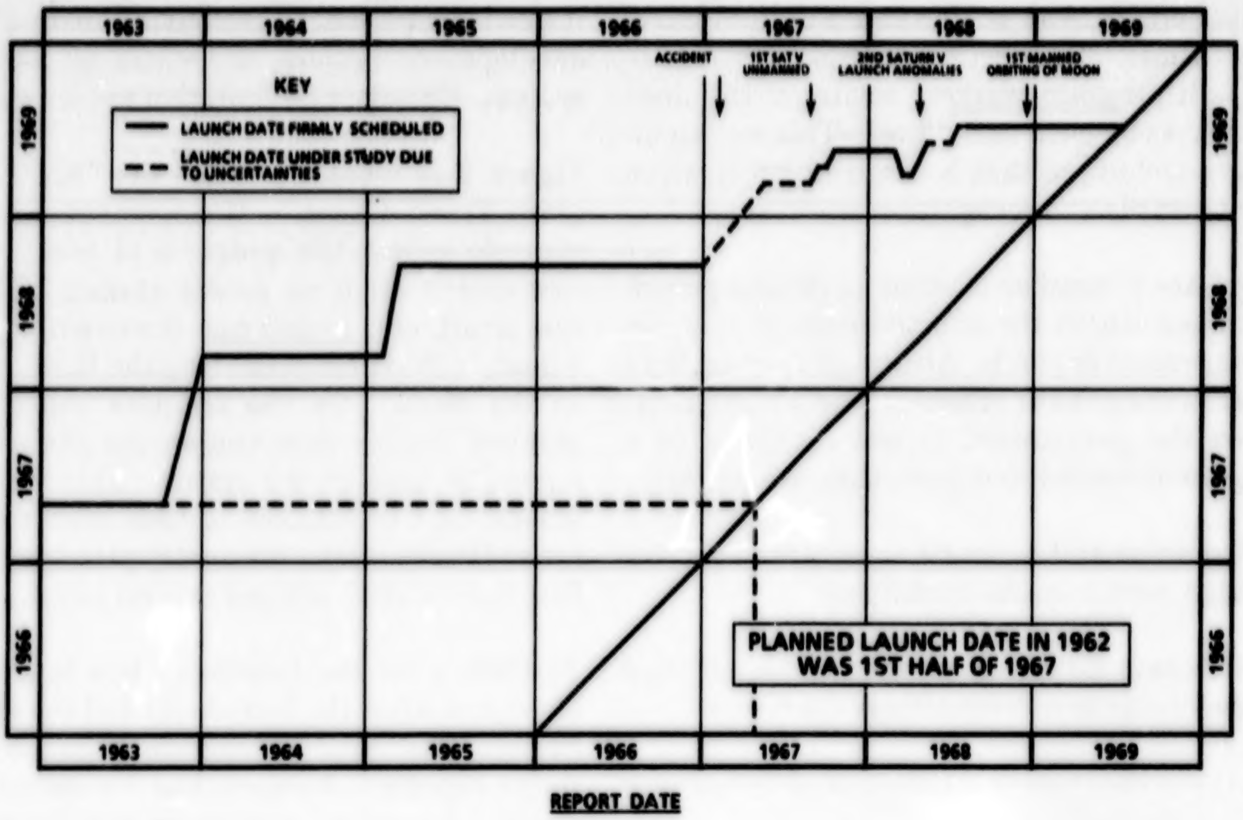


Figure 2. The Apollo Program Trend Chart.

Space Flight organization of NASA Headquarters. Note that the Apollo Program box appears in the NASA command structure just as any functional or institutional segment would appear, reporting to the Associate Administrator, who, in turn, reports directly to the NASA Administrator.

Figure 4 depicts the Apollo Program management structure. Some of its features require special attention in order to thoroughly understand the actual arrangement.

The Associate Administrator for Manned Space Flight at the same time chaired the Management Council. Its membership consisted of the Associate Administrator's deputies and the field Center directors with their deputies. Acting in a directive role, the Associate Administrator passed instructions to the field Center or to the Apollo Program Office. In turn, the Center director, through membership on the Management Council, had a direct voice in shaping the program direction which comes to the Center for execution. The Council met once a month or at the direction of the Associate Administrator, its Chairman. At these meetings, the Apollo Program Director in Washington and the project managers of the field Centers reported to the Council. The project managers included the Saturn V Manager from the Marshall Space Flight Center, the Apollo Spacecraft Manager from the Manned Spacecraft Center, and the Manager for Apollo launch preparation at the Kennedy Space Center.

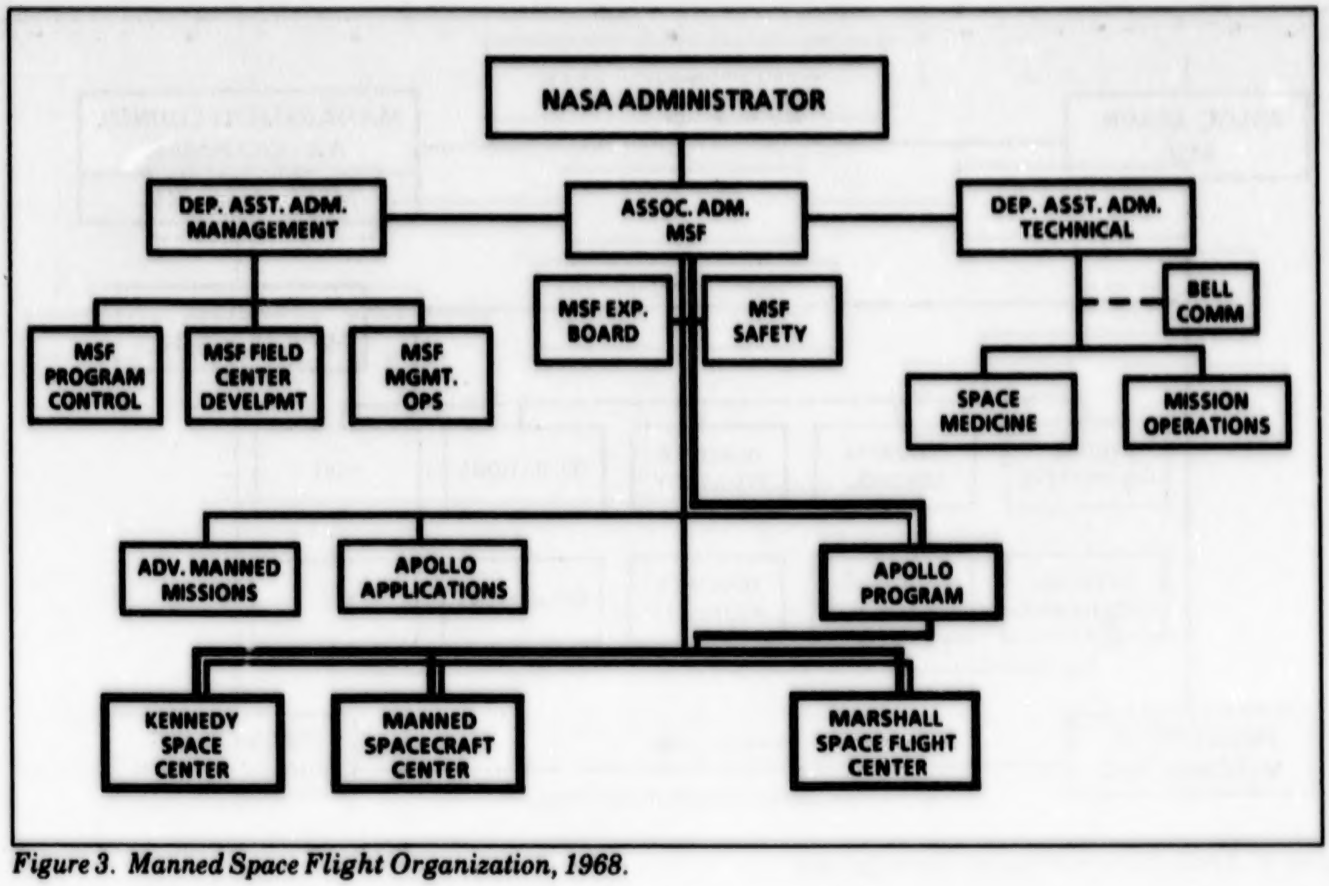

NASA ADMINISTRATOR
DEP. ASST. ADM. MANAGEMENT
ASSOC. ADM. MSF
DEP. ASST. ADM. TECHNICAL
MSF EXP. BOARD
MSF SAFETY
BELL COMM
MSF PROGRAM CONTROL
MSF FIELD CENTER DEVELPMT
MSF MGMT. OPS
SPACE MEDICINE
MISSION OPERATIONS
ADV. MANNED MISSIONS
APOLLO APPLICATIONS
APOLLO PROGRAM
KENNEDY SPACE CENTER
MANNED SPACECRAFT CENTER
MARSHALL SPACE FLIGHT CENTER

Figure 3. Manned Space Flight Organization, 1968.

The topic of these presentations covered, among others, the following principal areas:

- Where did the money go and can we manage with the allotted funds remaining?
- What planned tasks have been accomplished and can we meet the projected schedule?
- What are our major technical and programmatic problems and what previously unforeseen actions must be taken to overcome them?
- What are our motivational problems?

The Design Certification Review (DCR) was part of the Management Council meetings and the certification was signed by the Chairman and the three Center directors.

Five organizational segments reported directly to the Apollo Program Office. They were the major units through which the program director managed the program. Corresponding to this organization was the field Center's organization with exactly the same segments. The names of the boxes are self-explanatory. A similar organizational structure was set up at the prime contractors, to the extent that such was necessary.

Figure 5 indicates the manner in which the contractors, prime and sub, may relate to a project. The diagram in this case pertains to the Saturn Project at the Marshall Space Flight Center and the corresponding contractor structure. Of particular interest here is the relationship between the institutional technical capability and the project manager on the one hand, and this capability and the contractor on the other.

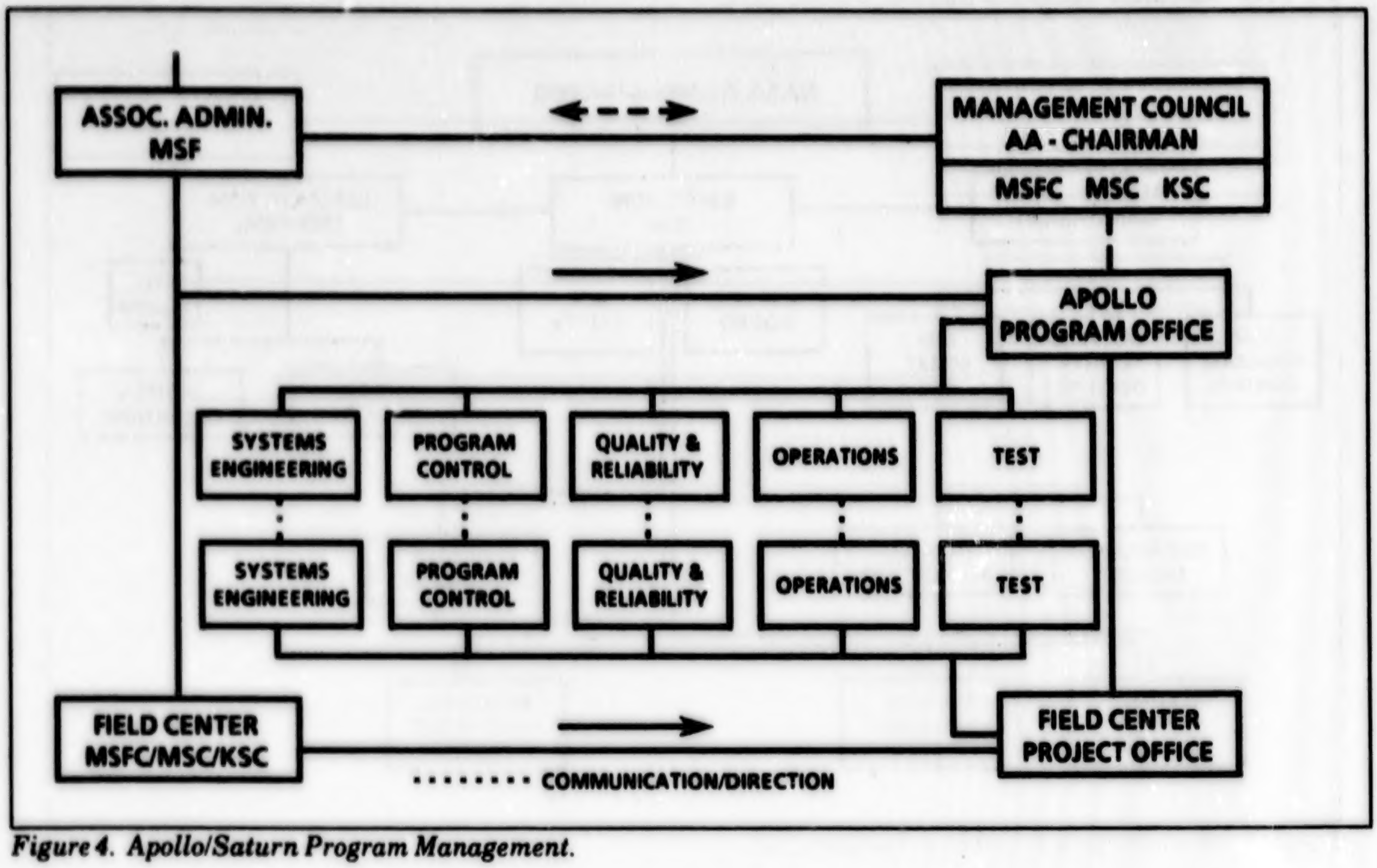

ASSOC. ADMIN. MSF
MANAGEMENT COUNCIL AA - CHAIRMAN
MSFC MSC KSC
APOLLO PROGRAM OFFICE
SYSTEMS ENGINEERING
PROGRAM CONTROL
QUALITY & RELIABILITY
OPERATIONS
TEST
SYSTEMS ENGINEERING
PROGRAM CONTROL
QUALITY & RELIABILITY
OPERATIONS
TEST
FIELD CENTER MSFC/MSC/KSC
FIELD CENTER PROJECT OFFICE
.... COMMUNICATION/DIRECTION

Figure 4. Apollo/Saturn Program Management.

The ready access that the project director had to the engineering expertise of the Center was of particular importance in maintaining real-time project visibility and control. For maximum effectiveness, the institutional capability must respond to specific requests and maintain continuing surveillance, thus exposing unsatisfactory technical trends early enough to allow preventive measures. As an additional contribution, the in-house technical capability may and frequently did respond to requests from the prime contractor.

Other areas of the Apollo Program that were of great significance to the program management are:

- The system logistics: that is, transportation of hardware from manufacturer to launching site, supply of propellants, pressurants, spare parts, etc.;
- The safety and security system;
- Astronaut training with all the training hardware and simulators;
- The medical aspects of the expedition;
- The organization and management of the scientific endeavor;
- The determination of the landing sites on the Moon;
- The ground organization and the worldwide network for tracking and data acquisition during a mission. Sixteen stations distributed around the Earth had to be operated, many in foreign countries; and
- Finally, the planning of the mission operation and the mission operation itself.

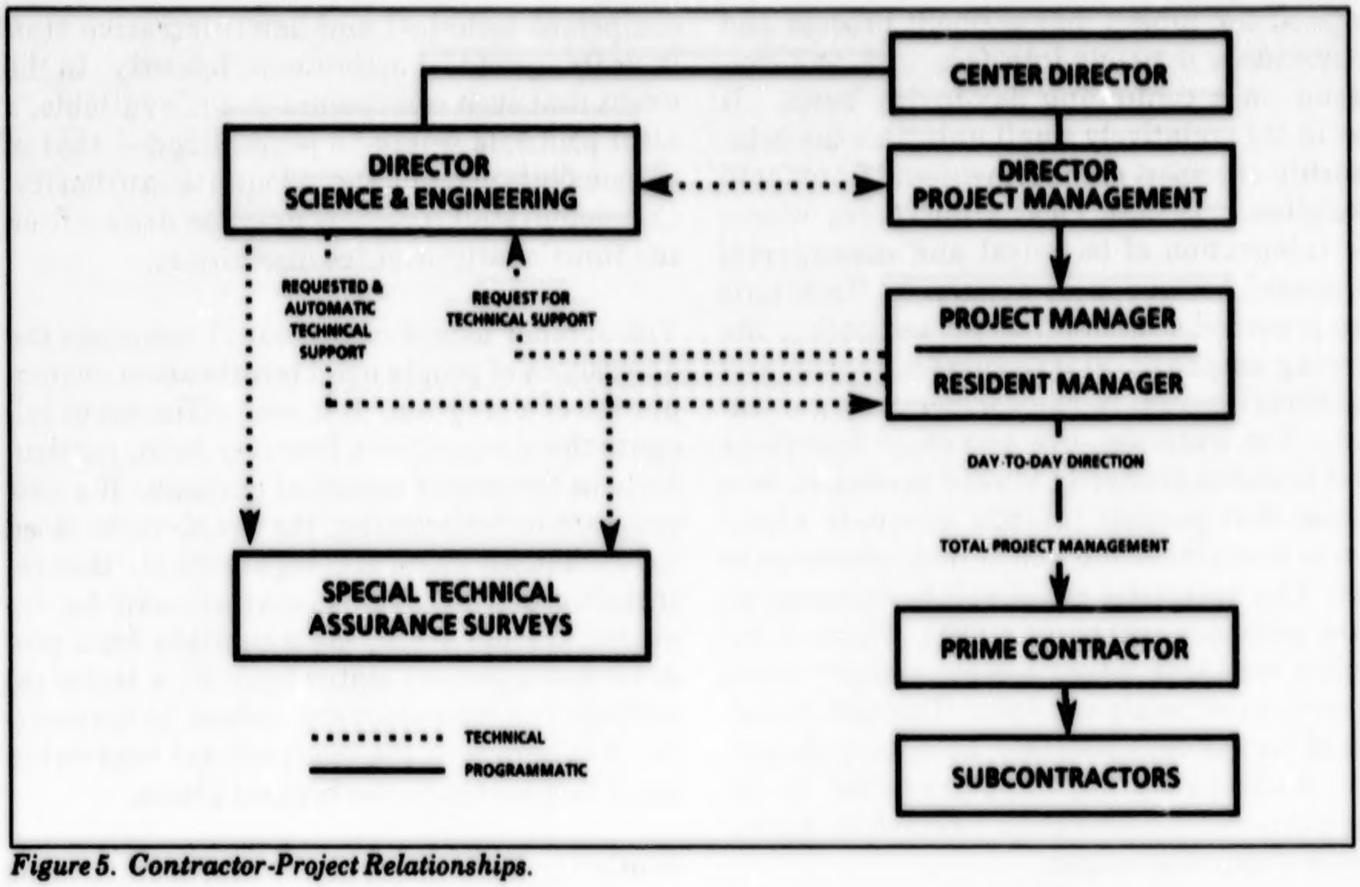

CENTER DIRECTOR
DIRECTOR SCIENCE & ENGINEERING
DIRECTOR PROJECT MANAGEMENT
REQUESTED & AUTOMATIC TECHNICAL SUPPORT
REQUEST FOR TECHNICAL SUPPORT
PROJECT MANAGER
RESIDENT MANAGER
DAY-TO-DAY DIRECTION
TOTAL PROJECT MANAGEMENT
SPECIAL TECHNICAL ASSURANCE SURVEYS
PRIME CONTRACTOR
SUBCONTRACTORS
TECHNICAL
PROGRAMMATIC

Figure 5. Contractor-Project Relationships.

All these subjects comprise major activities which had to be integrated into an overall management system. In order to provide maximum control and visibility of the system and of all occurrences in the program, a system of control rooms was established. These rooms contained up-to-date information and displays and were located at the Apollo Program Director's Office in Washington and at the three Manned Space Flight Centers and at each prime contractor. Each control room was equipped to permit conference calls between Headquarters and the Centers. This communication system furnished a means for greatly accelerating the decision-making process.

I should now like to explain the matter of integrating the project office, the functional elements of the institutional organization, and the contractor. Three categories of concern emerge. First, there are the hardware, systems and subsystems specialists who devote attention to the delivery of items that are technically adequate and qualified for mission performance. Second, there are the specialists who approach the project from the point of view of controlling costs and schedules. As the third organizational element in the grouping, there is the on-site resident management office. Staffing this latter element were specialists located at the contractor's facility to assure that project management interests were advanced and that decisions were made and implemented within the designated scope of authority of the resident group.

This resident element proved to be a most important link between government and contractor activities. To expedite decisions, the resident manager required functional support, which was provided by specialized, on-site contract administration and technical engineering staff. These support personnel were assigned from parent functional organizations of the responsible Center. Within well-established limits, these people could make decisions "on the spot" or commit the parent office or function at the Center. The result was to speed the project management process and to provide a dynamic interface with the contractor on a continuing day-to-day basis. It was in this relatively small unit that the relationship of project management and functional discipline was most clearly mirrored; where the integration of technical and managerial personnel became most apparent. This unit also provided a mechanism for tempering the varying emphasis on government project and functional groups in the contractor organization. For example, the technical functions tend to strive primarily toward perfection to a degree that possibly inhibits adequate attention to manufacturing and launch schedules or cost. The contractor could well be oriented toward schedule, costs and profits, whereas the project manager might weigh concern more heavily on schedule and costs. Through the office of the resident manager, an automatic system of checks and balances developed to the end that each consideration received its appropriate share of attention.

Conclusion

A number of the points I have raised offer a high potential for solving difficult problems. One of these is the technique of contractor penetration to obtain visibility. There is an understandably strong desire on the part of industry to take the control and the funding and to do the job with but minor government intervention. However, there have been too many cases of severe program impacts when this alternative to close contractor surveillance has been permitted. The restiveness that stemmed from such close control gradually dissipated early in the Apollo Program as the benefits accruing from the industry-government teams approach were revealed.

In forming the project or program offices, it is clear that the manager must have control of competent technical and administrative staff in order to conduct activities efficiently. In the event that such competence is not available, a vital principle would be jeopardized -- that of responsibility requiring adequate authority. Competent staff members must be drawn from the functionally oriented disciplines.

Yet another aspect of personnel concerns the disposition of people upon termination or completion of a program. It is not sufficient to relegate them to positions formerly held, particularly in the case of technical persons. If a new program is forthcoming, the problem is eased somewhat, although it is highly likely that retraining or refresher education will be required. In any event, the transition from program management status back to a technical activity in a laboratory can indeed be traumatic. It is here that the institutional leadership must be asserted on the highest plane.

While centralized program management has many values, of prime importance is the assignment of all responsibility to single organizational management structures, pyramiding into a single strong personality. This prevents fragmenting vital responsibility among numerous individuals with subsequent loss in time, money, manpower and technical progress. Of course with the responsibility, the manager must have commensurate authority to resolve technical, financial, production and other problems that otherwise require coordination and approval in separate channels at different echelons. And the manager must have clear, concise communications flowing in all directions.

With these tools, program management can apply all the capabilities -- technological, sociological, economic, or whatever -- to any project and systems problem, however large or complex it might be.

NASA Organization and Management from 1961 to 1965: The Vision and the Reality

by Erasmus H. Kloman
Senior Research Associate
National Academy of Public Administration

NASA Administrator James E. Webb had been in office only three months before President Kennedy announced his decision for a manned lunar landing. Webb was in charge of a rapid acceleration in the NASA budget and staff. While the program build-up was under way, Webb instigated a series of internal management analyses and reviews, some of which were extensions of initiatives taken by his predecessor. One of the major problem areas first explored was the Headquarters-Field Center relationship, one which has been studied and reorganized almost continuously ever since.

During NASA's first three years, the field Centers reported to Headquarters program directors rather than to general management. There were two major weaknesses in this system. The subordination of Center directors to Headquarters program directors tended to create a gulf between the field and Headquarters. Secondly, the Headquarters program offices tended to be more narrowly focused than the more multi-purpose field Centers, and there was a mismatch in the missions and institutional interests of the various field Centers and their respective program offices in Washington.

In November 1961, the first of many subsequent reorganizations was authorized, putting the field Centers directly under the Associate Administrator, Robert C. Seamans, Jr., who was later to become Air Force Secretary. The field Centers continued to receive specific program direction from the program offices, but were no longer subordinate to the program Associate Administrators. Earlier in his first year, Webb had authorized another major reorganization, establishing a new Office of Programs and an Office of Administration based on a unit previously called the Office of Business Administration. The Office of Programs was responsible for integrating NASA's program planning, facilities coordination, management planning, resources programming and project reviews. As a means of exercising this function, the office established the Program Approval Document (PAD) system to govern the process of Headquarters review of specific programs. This new office and the Office of Administration both reported to Robert Seamans.

The 1961 reorganization fell short of expectations. Three reasons attributed to the failure were: 1) the tendency of the new structure to create a "free-for-all" between the field Centers and Headquarters, 2) the undermining of the authority of Headquarters program directors to give direction over anything but specific, discrete projects, and 3) the imposition of a crushing overload of responsibilities on a single Associate Administrator, Robert Seamans. Although the 1961 reorganization had served to remind Centers that NASA had a central purpose to which all local interests were secondary, it could not be maintained as a permanent arrangement.

In November 1963, the structure reverted back to one in which field Centers reported to the Headquarters program office responsible for their primary program activities. As Webb observed several years later, the purpose of the 1963 reorganization was to emphasize that a Headquarters program director, newly designated as an "Associate Administrator," was "a guy running his show . . . and that he ought to think of himself as nearly as possible doing the total job. He had to present his program to Congress he wasn't just an internal manager. For his area he had almost as broad responsibility as the Administrator."[1]

Nevertheless, important aspects of Seamans' role as "general manager" remained unchanged. The program Associate Administrators continued to meet regularly with him, and he continued to oversee the various internal management systems such as the PAD process. The decision to switch the Field Center-Headquarters relationship back to what had existed only two years before illustrates Webb's belief in the importance of flexibility and adaptability. In Space Age Management: The Large-scale Approach, a volume based on his Columbia-McKinsey lectures delivered in 1968, Webb wrote as follows: "Our constant effort has been to obtain a sufficient real-time feedback from the fastest-moving parts of our substantive and administrative activities to enable us to alter our course as needed. We have sought patterns of organization and administration that facilitated fast reaction times to signals of incipient failure or emerging opportunity."[2]

What Webb recognized as an essential part of the ethos of NASA was the need for a continuing process of adjustment and adaptation to dynamics of change both within and outside the agency. He saw that NASA could not be governed by the old-style principles of public administration which sought to assure stability and order within a rigid hierarchical framework. To accommodate the fast-moving scientific and technological projects for which NASA provided a home, NASA would have to stay loose. The components of the organization: the field Centers and Headquarters; the program and project offices imposed on a matrix organizational structure; the complex of in-house management; and the much greater corpus of outside contractors -- this vast array of disparate parts could never be expected to become a stable and harmonious entity. In an unpredictable and sometimes turbulent environment, Webb recognized a need to maintain a desired level of disequilibrium.

This philosophical approach has been accepted within NASA throughout the post-Webb era, but with varying degrees of commitment. Much of NASA's subsequent organizational history has evolved around the weighing of tradeoffs between the risk-taking, free-wheeling management style, and the search for more traditional values of order, continuity and stability.

Centralization versus Decentralization

The search for the best organizational pattern has also entailed a continuing quest for the best blend of centralization and decentralization. Several issues have been critical to the structure of the reporting relationships between the field and Headquarters.

1. How to maintain the desired degree of autonomy and independent initiative at the field Center level.

2. How to assure that the Headquarters program Associate Administrators exercise adequate control over their respective programs without engaging in "micro-management."

3. How to provide for adequate communications between the Administrator and field Center directors without overwhelming the Administrator or undercutting the program Associate Administrator.

4. How to find an individual with the right personality to serve in the Headquarters office to which the field Centers report.

Experience with the several types of reporting relationships suggests that there is no single "right" way to set them up. What works at one time may not necessarily work at another. The arrangement should be responsive to the management imperatives of the contemporary environment. In any case, the success of the total complex of reporting relationships depends on the crossfeed of significant and meaningful information among those having a "need to know" and the timely upward flow of the important information to whomever is responsible for the agency's general management.

In the early days of NASA, the field Centers tended to have more discrete roles and thus to work only or mostly on programs falling under a single Headquarters program office. There was an obvious logic in clustering groups of Centers under the several program offices at Headquarters. Over the years the field Centers, each seeking to build capability to compete for future projects, expanded their respective areas of competence. At the same time, as the dimensions of the larger manned flight programs such as the Shuttle grew, the number of Centers working on a single program increased correspondingly. Thus a new configuration evolved in which most of the Centers were working on programs falling under more than one Headquarters program office.

Personalities and Personal Relations

The question of personality cited above is a crucially important -- some would say the most important -- factor in determining how well the Headquarters-Field Center reporting relationship works. Obviously it is essential that the individual to whom the Center directors report in Headquarters be someone in whom they can place their confidence. The job calls for a rare combination of experience and talent -- including an ability to understand the Center directors and to represent them in an even-handed way -- and a toughness in implementing sometimes unwelcome decisions.

The relationships between Headquarters and the field reflect in large measure the chemistry existing among the personalities of the Administrator, the Deputy, the Associate Administrators for programs, and Center directors. Ideally, all these players should fit together as a closely knit and mutually supportive team. They should be able to understand each others' needs and subordinate the goals of their respective positions and organizations to the broader goals of the agency.

Strength Through Diversity

Since the real world is, in fact, far from the ideal, a state of such harmony is always elusive. People in Washington and people in the field can never have the same perspectives and values. The Washington outlook is dominated by the power politics of the nation's capital and the struggle to maintain NASA's place in the federal establishment. Center outlooks are more oriented to specific research and development tasks to be accomplished. Moreover, from Center to Center there is a built-in rivalry. Each Center nourishes an absolute conviction that it is the best of the lot. Each Center is hard at work to make its own place strong and secure in whatever lies ahead for NASA. No Center is willing to reveal its entire hand to other Centers or, for that matter, to Headquarters. Nevertheless, Centers can and do cooperate effectively on agency programs and projects. In the process, they share facilities, people, and ideas. Institutional loyalties, however, tend for the most part to stay fixed.

Thus NASA is significantly different from many large decentralized organizations in either the public or private sector. Compared with the military establishment, for example, NASA often appears to resemble the collection of military services operating with considerable rivalry under the Department of Defense rather than a single military service. Indeed, the competition among the Centers is mostly a positive force spurring each Center to excel in comparison with its peers. In the private sector the closest analogy would be a loosely-knit conglomerate with autonomous profit centers rather than a fully integrated single-line company.

In the case of either the public or the private analogy, all the elements of the organization share common goals but may differ sharply on the means for reaching those ends. The job of top management is to see that the best means are selected out of the competing ideas advanced by the various contenders in the organization. The NASA Administrator must attend to a great deal of advice, often conflicting, from contractors, the scientific community, and the numerous NASA advisory bodies. The Administrator's task is to maintain the U.S. position of strength in our aeronautics and space programs, building on the diversity of policies, programs and resources over which varying degrees of control are exercised.

Once an idea has prevailed in the internal competition among all the technical and professional experts, the Administrator must sell the idea to those who hold the purse strings. Thus a NASA Administrator will be judged in large measure by success or failure in persuading the President, the Office of Management and Budget, and the Congress which programs will best support the aeronautical research and space interests of the nation.

The Triumvirate

Another hallmark of Webb's administration was his acceptance of the concept of shared decision-making at the top. We have noted the important role played by Seamans as an internal manager. Hugh L. Dryden, who had formerly headed the National Advisory Committee for Aeronautics and served as NASA Deputy Administrator under Glennan, had remained in the deputy position under Webb. Dryden was a highly respected aerospace scientist with a vast network of connections throughout the scientific community.

During the years until Dryden's death in 1965, the three top leaders of NASA -- Webb, Dryden, and Seamans -- formed a triumvirate in which all three worked as a team in every sense of the word. Webb insisted that each was to be a full-scale participant in administrative as well as substantive decisions. As James Beggs noted in the inaugural lecture of the National Academy of Public Administration's James E. Webb Fund for Excellence in Public Administration:

> *"It was agreed that in policy and practice no one of the three would act to do violence to the strongly-held views of the other two. The three were committed to ensure that all of NASA's leadership needs were considered and met at all levels."*

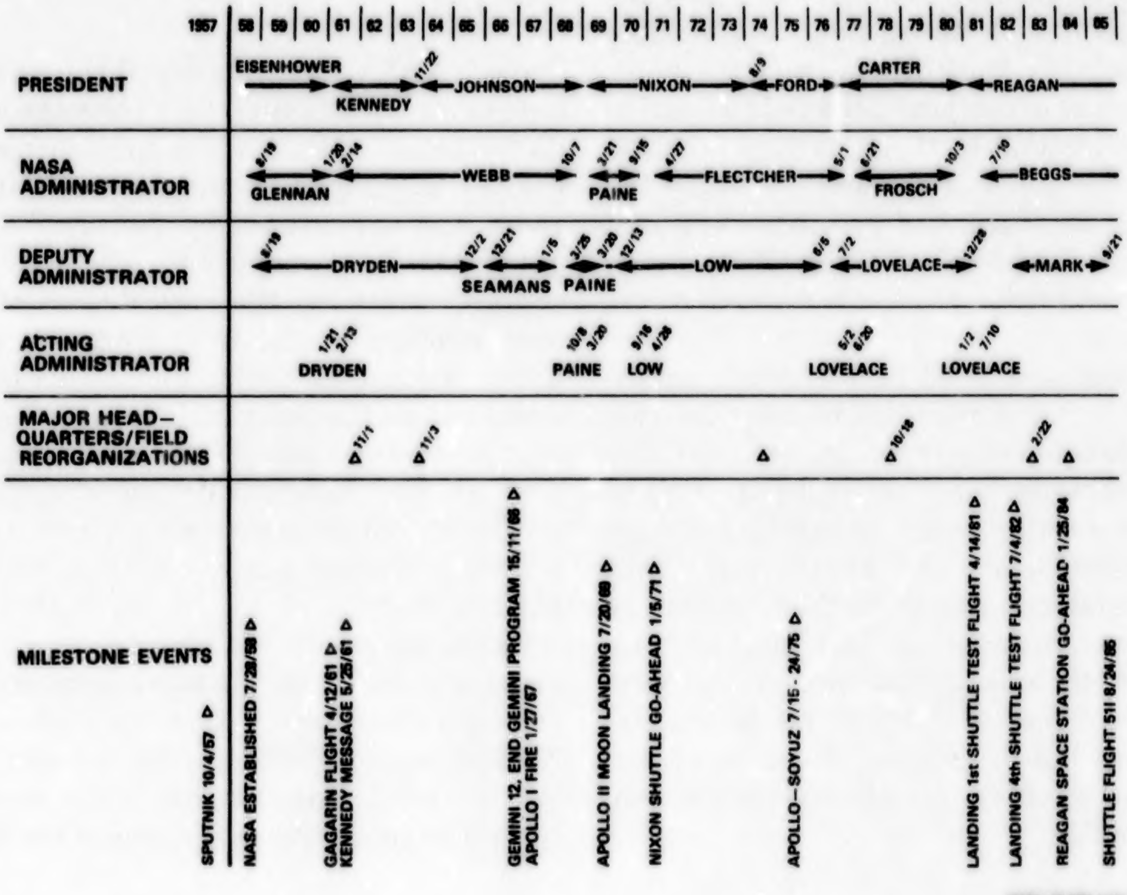
Webb himself described the three-man relationship as one which intentionally bound the three men in "hoops of iron." A major application of this policy was a process requiring that all procurement decisions over $5 million be made by all three men. They reviewed the recommendations of a technical/managerial team representing the most informed thinking on any individual procurement up to their level. Each final selection was made by the top three executives.[3]

Seeking Outside Advice

One of Webb's guiding principles was to spread the toughest problems over the largest possible number of capable minds. As the member of the triumverate who served as "Mr. Outside," Webb was especially interested in seeking outside advice. Nearly ninety cents out of every NASA budget dollar was spent outside the agency, mainly in contracts with the aerospace industry, which provided a major source of advise on engineering and technical questions. Webb also fostered an imposing network of university and academic relationships. Through the Sustaining University Program initiated by Webb in 1961, NASA over the next decade channeled more than $100 million to academic institutions in support of research and the doctoral programs of more than 5,000 scientists and engineers. An additional $42 million was channeled to universities for construction of research facilities on 31 campuses. Webb was thus able to tap into the best thinking of industry, the academic community, and the able people whom he gathered together within the agency. He extensively used management consultant teams and individuals, and the many special advisory committees and panels set up by the National Academy of Sciences.

Because of his special interest in administration and management, Webb was elected President of the American Society for Public Administration (ASPA) in 1966. He soon came to see the need for an organization which could perform an equivalent role in public administration to that of the National Academy of Sciences in its field. He felt that NASA and other government agencies should have access to a source of trusted counsel that could give advice on questions pertaining to management and administration. Accordingly, Webb organized those who had preceded him as ASPA presidents to become the founders of the National Academy of Public Administration.

NASA provided the initial funds that permitted the academy to open its doors while conducting some initial studies of NASA management. The granting of a federal charter to the Academy in 1984 represented a major milestone in the fulfillment of Webb's vision 17 years earlier.



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Reorganization: A NASA Management Refrain

As noted in the earlier discussion of the reorganization during the Webb administration, the Field Center-Headquarters reporting relationship has undergone many permutations throughout the agency's history.

In the spring of 1974, Dr. Fletcher and his colleagues began to believe that in a period of budget reduction such as NASA was experiencing, the Headquarters-Field Center reporting alignment was no longer responsive to overall agency needs. Accordingly, another major reorganization was implemented, establishing for the first time an Office of Associate Administrator for Center Operations. Two subsidiary offices, one for Institutional Management and a second for Headquarters Administration, were set up under this new Associate Administrator.[4] Again, as in the period from 1961 to 1963, the field Centers reported to a single Headquarters office. The new Office of Institutional Management, responsible for agency-wide institutional management, was a response to concern in the field about inadequate attention in Headquarters program offices to institutional resources, namely the equipment, facilities, and personnel required to sustain the technical and scientific capability of the Centers.[5]

In his second year in office, Fletcher's successor, Dr. Robert A. Frosch, found that the Field Center-Headquarters reporting relationship put into effect four years earlier by Dr. Fletcher was not working to the satisfaction of most of the key people involved. Frosch instituted a first-ever system in which all the Centers and all the program Associate Administrators reported directly to him. The new system gave the Center directors direct access to the Administrator, but it stretched the span of control beyond what is generally regarded as reasonable limits.

The fifth reorganization of the Headquarters-Field Center relationship was carried out by the next Administrator, James E. Beggs, who reinstated the system in which the field Centers report in clusters to the program offices. This configuration ran into some of the same types of problems confronted in the past under similar arrangements. Each of the Centers worked for more than one program office. The Centers felt that too little concern was given by their respective program offices to the institutional health of the Centers. Center directors were not satisfied that the program offices represented their interests in Headquarters decision-making. Old refrains were being heard again and another reorganization appeared to be in the making.

Looking Inside Today's NASA

(Note: Although this article was written in 1985, some of the insights are applicable today. -- Editor*)*

Today's NASA retains many of the same attributes that have distinguished the agency since its formation. Much of the management philosophy developed in the agency's first ten years and articulated by James Webb still guides today's management. The basic organizational structure, the high degree of autonomy accorded to the field Centers, and the heavy reliance on contractors as the principal agents to do the work still remain as important features of the NASA *modus operandi*. Perhaps most remarkable [as of 1985] is the continuity of personnel. NASA has one of the lowest turnover rates of any federal agency. Most of NASA's highly skilled technical and professional employees know that the excitement and challenge of their jobs cannot be matched elsewhere. Even though many of NASA's senior staff have skills and talents that are readily marketable in the more highly paid private sector, they choose not to move.

The negative side of this personnel profile is the fact that many NASA employees now approaching retirement eligibility are likely to leave in a mass exodus over the next several years. This problem is compounded by a scarcity of potential leaders between the ages of 30 and 40 -- a gap caused by low recruiting levels in the cutback period of the 1970s. Recently, however, NASA has had great success in recruiting highly qualified college freshouts. The NASA mission still attracts topflight scientists, engineers, and technicians.

Regardless of its recent success in attracting quality personnel, NASA suffers today from many of the same exigencies that afflict other departments and agencies of the federal government. The environment for these federal organizations has been severely damaged by the anti-bureaucratic rhetoric so prominent in recent political campaigns and the excessive zeal of those seeking to gut the federal workforce. Equally damaging has been the vast array of rules and regulations, promulgated largely in response to Congressional pressures, that have resulted in tighter limits on the ability of government managers to manage.

The vigor and vitality of NASA in its early years came in large measure from the sense within NASA that the agency was its own master. Congress appropriated the money; NASA executed the program. The management of the agency was more than willing to assume responsibility and accountability for the expenditure of the public funds entrusted to it.

Today's management climate is vastly different from that of NASA's early years. Like other federal agencies, NASA finds itself under the close scrutiny of numerous Congressional committees, each with its own particular agenda and priorities and each seeking information in more and more detail. With such information the committees can carry out their oversight function to the point of what often appears as micro-management.

A major instrument of congressional oversight is the General Accounting Office (GAO). Staff of GAO, working with the greatly expanded (some would say overblown) staff of the Congressional committees, are constantly looking over the shoulders of all federal managers. At the same time, the central agencies of the executive branch -- the Office of Management and Budget, the Office of Personnel Management, and the General Services Administration -- have imposed layer upon layer of regulations resulting in increasingly centralized management systems. As a result, managers at all levels are forced to devote excessive amounts of their time and energies to the filing of forms and writing of reports. In such basic areas as personnel, procurement, travel, and budget management, managers find that they have only limited freedom of action. During NASA's early days, decisions were made at all levels of management on a timely basis, but today's decision-making process moves more slowly and ponderously. Whereas key individuals or small groups took responsibility for decisions in the past, today that responsibility tends to be spread out among larger groups or committees.[6]

An inevitable result of having so many watchdogs and so many centralized regulatory systems is inhibiting initiative and the willingness to innovate or take risks. Instead of delegating responsibility to lower levels, each level of management feels compelled to retain tighter controls and more decision-making authority. Thus NASA Headquarters program offices exercise what the field Centers regard as micro-management, and the working relationship between the two levels is strained. At lower levels throughout the agency, managers are diverted from their principal tasks by the need to comply with the regulatory overload.

Despite these negative forces working against good management, NASA stands out as one of the best run agencies in the federal establishment. The high standard of NASA performance owes much to the innate drive of NASA personnel to strive for excellence. NASA's workforce, by virtue of its high levels of education, training, and motivation, represents an elite corps. They take great personal pride in their participation in a program which is so highly visible and so much a symbol of American leadership in science and technology. The continuing high level of job satisfaction in the agency ties directly into the fast-paced technical challenges inherent in the lofty goals set out in the NASA charter and the commitment of space activities "to peaceful purposes for the benefit of all mankind."

While much has remained constant in the NASA physiognomy, significant change is under way in the nature of NASA's mission. Until the era of the Shuttle, that mission consisted mainly of various scientific exploration and technology development programs of limited duration. As an R&D organization, NASA was by nature devoid of any operational role. The implicit prevailing assumption was that once a space science mission had been accomplished, the results would be turned over to the scientific community for investigation. Likewise, in the aeronautics research area, findings were turned over either to potential commercial users or to the military establishment. The Space Shuttle and the Space Station, each being long-term operational enterprises, pose a new set of questions with respect to the most appropriate institutional home.

The question of the best institutional base for the Shuttle came up for discussion and analysis as the development phase got under way. In 1977, James Beggs, then Executive Vice President of General Dynamics, chaired a panel of the National Academy of Public Administration that considered various organizational alternatives for the Shuttle. The report of the panel concluded that unless and until the economics of the Shuttle provided a basis for attracting private investment, the best organizational alternative was to retain the Shuttle in NASA.[7]

In the eight years since that study was conducted, the prospects for turning the Shuttle into a net revenue producer have changed for the worse rather than for the better. Although many in NASA would welcome an opportunity to hand over the Shuttle to some other organization in order to refocus NASA on its traditional R&D tasks, there are no other appropriate alternatives in sight.

Looking ahead to the point in the 1990s when the Space Station is scheduled to become operational, it appears that a similar set of questions will arise. Indeed, for as long as one can see clearly into the future, it seems that the NASA mission will include, in addition to the traditional time-limited R&D activities, a responsibility for the maintenance of operating systems providing access to and a permanent manned presence in space. Six field Centers are now involved in the Space Station program. Such major changes under way in the mission of NASA will probably call for further agency-wide organizational adjustment and restructuring.

-- October 1985

Edited and excerpted from sections of NASA: The Vision and the Reality by Erasmus H. Kloman. National Academy of Public Administration (GPO: 1986-491-574: 40015). Used with permission.

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6. *An assessment of how excessive controls constrain federal managers is presented in Revitalizing Federal Management: Managers and their Overburdened Systems, Report by a Panel of the National Academy of Public Administration (November, 1983).*

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Management and Budget Lessons
The Space Shuttle Program

by Humboldt C. Mandell, Jr., Ph.D
Johnson Space Center

After each major manned space program, the Johnson Space Center has conducted research, written histories, and analyzed management methods to scrutinize the past for weaknesses and mistakes that can be avoided in the future. These efforts have had three results:

1. Some practices and weaknesses have been influenced and changed. Among specific lessons learned are the need for extended program definition phases, resistance to pressures to estimate costs on the low side, incorporation of adequate cost reserves into the planning process, accurate initial estimates to provide program stability, and the increased involvement of NASA analysts in the prediction of program budgets.

2. Some problems have continued because the cultural acceptance of practices has made them difficult to modify. For example, the lack of emphasis on the "budget year" throughout the manned space program contributed to budgetary problems, but the practices have remained relatively unchanged from the Apollo program up to the present time.

3. Some obvious problems are inherently a part of government program management systems and are beyond the capability of any agency to influence. An example of this is the divided management responsibility, which has been a part of some large NASA programs, compromising the unity of command. In a political society, such compromises are a way of life and cannot be easily changed by the agency itself.

Some reform of the NASA budget process has been called for by study groups, along with closer coupling of the design and cost estimating processes, and improvement of performance management/measurement systems.

Analysis of Previous Lessons Learned

In 1971, at the beginning of the Space Shuttle Program, an extensive interview process was conducted at Johnson Space Center to determine what management lessons had been learned by the aerospace industry which might help avoid problems in managing the Space Shuttle development. A structured set of interviews was conducted with senior managers of teams from the highest technology aeronautical programs then existing. These included the SR-71 Strategic Reconnaissance Aircraft of the United States Air Force (Clarence "Kelly" Johnson, Program Manager, Lockheed Aircraft Co.); the Boeing 700 series of aircraft (George Schairer, Vice President, R&D, Boeing Airplane Company); the B-58 (Robert Widmer, Vice President, General Dynamics/Ft. Worth), and numerous others.

Perhaps the most striking result of the activity was the general management consensus concerning ways to reduce costs in government programs, particularly when the findings are compared to current NASA management practices.

The study reached the somewhat subjective conclusions that to reduce program costs, NASA should:

1. State requirements as objectives, and leave them relatively unconstrained.
2. Not start building flight hardware until all major technological uncertainties have been resolved.
3. Utilize small, hand-picked government program offices and contractor teams.
4. Eliminate (or greatly reduce) government-imposed changes.
5. Allow contractors maximum autonomy.
6. Once program definition has resolved major technological uncertainties, complete the development process as quickly as possible.

NASA management agreed to try many of these potential cost-saving cultural differences. However, the cultural inheritance, a result of using many of the same management and contractor teams from the Apollo program, soon overcame many planning ambitions. Except in a few notable areas, the original culture was not appreciably changed, except where it had to be adapted to survive the newly cost-constrained environment.

These 1971 studies further concluded that program cost estimates made within company engineering departments are generally adequate. However, since bidders usually underestimate costs to increase the likelihood of winning hardware contracts, overruns often occur. Research performed recently supports this finding; in fact, professional cost estimators have found that this buy-in effect has become one of the major contemporary problems of program cost analysis.

The 1971 studies observed that program control techniques similar to the DoD C/SCSC are effective and essential, but excessive control (or micro-management) is a deterrent to good performance. And finally, and probably most important to current and future programs, it was found that concurrent development of mutually dependent, high technology items is especially difficult unless strong unified management is provided.

Lessons Learned from Space Shuttle

Between 1977 and 1979 a series of studies was performed as a result of budgetary problems encountered in the peak funding years of the Space Shuttle program. These studies universally found that although the technical aspects of the program were being managed very well, some management problems existed. For example, the Day Committee, headed by LeRoy E. Day, found that peak funding problems had occurred as a result of almost universal inattention to the "budget year"; i.e., two years into the future. So much was the preoccupation with the current ("operating") year, that little attention was paid to the budget year. Often, contractor estimates were employed with little analysis to predict the program requirements. The Day Committee found that this problem could have been avoided by independent analysis of contractor estimates by the government. The committee also found that NASA in general did not apply enough analytical manpower to programmatic, especially budgetary, tasks. (The results of the studies were never published but are on file in the JSC Cost Estimation Data Bank.)

Prior to his departure from NASA, a Space Shuttle program manager was interviewed extensively to obtain his perspective on lessons learned from the program, particularly in the program management areas, including cost estimating and program control. He made the following observations.

- If the "bottom line" of success is obtaining a successful program result for the least money, then the management systems used were successful.

- No amount of money early in the program would have prevented the technical problems (the Space Shuttle Main Engine development problems and the Thermal Protection System tile problems, primarily).

- Ninety-five percent of the problems with our budget system have nothing to do with the mechanics of program control. They are more related to the way we organize and review our budget; pressures to be over-optimistic in the budgeting process; the interfaces we have with the Congress and the Administration; and coming to grips with problems we predict.

- Over-optimism is popular, and the process encourages it.

- The budget cycle can be improved. Budget calls probably should not dictate a schedule: project personnel should be asked to predict the schedules they can make and the dollars they need to make them.

- The prediction of program cost reserves should receive more emphasis, at all levels of the program. Program reviews should solicit issues and create a climate for resolving budget problems, not only technical issues. Reviews should emphasize the pedigree of cost and schedule estimates, the degree of optimism or pessimism (risk), and the likely program cost growth. Reviews should reflect the best estimates of cost reserves required for contingencies.

- Program control should emphasize quantitative measurement of progress, and focus on future projections based on past performance (e.g., manhours per foot of welds on the External Tank).

Program Control and Management Processes

A number of the factors influencing program success were also explored in a survey submitted to all senior managers of the Space Shuttle Program. Program managers were asked to rank management factors or processes which favorably influenced the outcome of the program. The most highly ranked items were:

1. Actions of the program manager (e.g., timely decision-making, effective management leadership);

2. Adequacy of the original cost estimates;

3. Actions of the program director (e.g., budget leadership, timely resolution of program conflicts);

4. NASA resource management processes employed by the program manager's staff; and

5. NASA resource management processes employed by the program director's staff.

The three least effective influences (neutral, slightly influential, or of negative influence) on program success were found to be: annual funding limitations by the OMB and Congress (this is an example of an influence completely outside the control of program management); the Cost Limit Review Board (CLRB) (a NASA Headquarters body that screened major changes); and the performance management/measurement system, which was ranked so low as to indicate that it might have even been counterproductive. At least, it was never used effectively.

Program managers were also asked to separately rank only the management processes which had had the most influence on the successful outcome of the program.

The most highly regarded process was the independent assessment function performed by the program office at JSC; second, the cost estimation process; third, the budgeting process (despite its flaws); and fourth and least effective, the performance management/measurement system employed.

A few other factors making major contributions to the favorable program cost outcome were: early system definition and configuration change control; change of program content (content was reduced at several points in the program); contractor willingness to accept risk; and good analogous data on which to base cost estimates.

Many of the managers said that too much management time was diverted from significant problems by excessive budget-related problems which occurred at the peak of the program. Six actions were suggested:

1. End overly close alliances with contractors;
2. Allow projects to keep change reserves within their budgets;
3. Plan the program to realistic resource limits;
4. Clarify the responsibilities of all program levels early in the program;
5. Treat escalation realistically; and,
6. Accurately assess development time.

Management responses were far from unanimous on these influences, however. For example, a former program director responded that accurate cost estimates at the outset of a program are often counterproductive, in that they provide ammunition for the opponents of the program. This lent further credibility to the conclusion that program proponents often do not want to know the true costs of a program, as total cost magnitudes can be a deterrent to successfully selling the program in the political environment.

Summary and Conclusions

Perhaps the major lesson to be learned from this type of analysis is that it is extremely difficult, primarily for reasons of cultural inertia, to change a management practice from one program generation to the next. Lessons learned are often either forgotten or not easily incorporated into the management culture.

I shall not repeat here the conclusions of the various studies mentioned above. However, I will describe a pattern that has emerged over two generations of analyses.

First, the **program planning process** has a significant effect on the outcome of a program. Programs with longer definition phases have proven to have the least cost and schedule overruns. Accurate initial budgets, provided by accurate program cost estimates, have universally been cited as a requirement for success. Accurate budgets have a stabilizing effect on the program; inaccurate budgets lead to the spending of inordinate management and other program resources on replanning, rescoping, recosting, and rescheduling activities.

Second, NASA has in the past not done the best possible job of **budgeting** during the peak years of a program, relying too heavily upon contractor cost projections, and not providing agency or program management with enough resource reserve flexibility to respond to program uncertainties. The NASA budget process must be reformed to provide more internal NASA analysis and less reliance upon contractor estimates. Far more emphasis on runout years is needed.

Third, there is enormous pressure at the beginning of a program to estimate the actual costs to be lower than historical trends might indicate. Lower estimates simply increase the probability that the program will overrun its costs. Program managers feel that they will be able to do better than their predecessors, and they are often willing to assume high risk in initial program estimates to help sell the program in the political arena.

Because hardware contracts are always competitively awarded, the proposer must tread a fine line between cost estimate credibility and the risk of losing out to a competitor offering a lower price. As David Novick, the father of modern cost estimation, said in 1962, "The incentives to estimate low are much greater than the penalties, if indeed there are penalties." In the quickly changing NASA environment, the contractor knows that if indeed a winning bid is too low, actual costs can be recovered through the acquisition process (usually cost-plus-fee), plus the cost of any changes made.

Fourth, NASA has consistently used three tiers of program offices, often large organizations with different points of view, despite evidence that many of the most successful aerospace programs have been effectively managed by very small program offices.

NASA has evolved to a management style which mixes government and private sector in the technological decision-making processes. This highly interactive style produces a technically superb product, but also causes an enormous change workload that often results in costly program changes. While a former Space Shuttle program manager denies that any nonessential changes were made, the process is driven by thousands of detailed changes, often stimulated by the NASA engineering community itself (as opposed to a process driven by broadly-stated program requirements). This process has been assessed by many senior program managers to be very costly.

Performance management/meaurement systems previously used by NASA have consistently been either ignored or blamed for not revealing problems in time to resolve them. Future systems should be designed to cope with the unique requirements of a particular program environment, as opposed to using systems from previous programs.

FOR FURTHER READING:

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Resources for NASA Managers

THE 'MANAGERS' ONLINE SERVICE (REVISED)

A current awareness service entitled MANAGERS is available online through the NASA/RECON system. Twenty citations and abstracts of books, journal articles, and reports are selected each week as those recent additions to the STI Database most likely to be of particular interest to NASA managers. The items included are updated every Monday morning.

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- U.S.-Soviet Space Relationships in the 1990's -- A U.S. Perspective on Policy Alternatives
- NASA's New University Engineering Space Research Programs
- The Law and Regulation of International Space Communication (book)

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BOOK REVIEWS

Effective Project Planning and Management: Getting the Job Done, by W. Glen Randolph and Barry Z. Posner, 1988. Prentice-Hall, Englewood Cliffs, N.J.

A self-help book for project managers? After eight years of leading seminars on effective project planning and management, these two professors with doctorates in business administration from University of Massachusetts wrote this book for managers in the broadest sense, from housekeepers to engineers. It begins with a self-scoring inventory and ends with inspirational advice to follow 10 simple rules.

The "planning" section consists of a catchy acronym for management by objectives: GO-CARTS. First, set a clear Goal. Then determine your Objectives. Establish Checkpoints (milestones), Activities (tasks), Relationships (among activities) and Time estimates. The S stands for Schedule, pictured in a bar or flow chart. Simple enough, and the authors apply the GO-CARTS to Noah's Ark, suggesting perhaps a better way to get ready for The Flood.

The "managing" section consists of another acronym: DRIVER. Direct people individually and as team members. Reinforce their commitment and Inform everyone of everything. Then build agreements (conflict resolution) that Vitalize team members, and Empower yourself and others with a greater sense of purpose in the project. Finally, Rule 10, encourage Risk-taking (creativity).

The rules and acronyms may seem contrived and overly simplistic, but the authors provide several lively anecdotes, cartoons and even comic strips.

The Leadership Factor, by John P. Kotter, 1988. The Free Press, New York.

Armed with questionnaires, interviews and case studies, Harvard Business School professor John Kotter identifies and validates four consecutive factors that create outstanding leadership: inborn capacity, early childhood experiences, formal education and career experiences. These factors seem to determine a great leader's keen mind, strong interpersonal skills, lofty integrity and high energy drives.

While such information is not exactly earth-shaking, Kotter's observation -- based upon empirical data -- is that "very few firms have sufficient people with those skills and assets." He describes this as an "increasingly serious problem." Lee Iacocca is the only leader singled out, and Johnson & Johnson the only management team that measures up to such leadership standards. Most of the failures are disguised by fictitious names.

To attract and keep better leaders, Kotter suggests a sophisticated recruiting effort (not based on "personnel" trivialities) to seek out the leaders of tomorrow; an attractive ("fun") work environment, free of games, politics and bureaucracy; challenging, decentralized opportunities; systematic, early identification of potential and development needs; and planned, formal development opportunities. The burden, he says, is on the shoulders of human resource professionals to look for and cultivate those who show innate and earned leadership potential, instead of being technically competent.

Thus, The Leadership Factor is more global and analytical than practical, a follow-on to his more popular The General Managers (1982) and Power and Influence (1985).

Kelly: More Than My Share of It All, by Clarence L. "Kelly" Johnson, 1985. The Smithsonian Press, Washington, D. C.

Kelly Johnson, perhaps the most honored aeronautical engineer alive today, is best known for his "Skunk Works" at Lockheed -- an innovative project management concept that produced the U-2 and SR-71 "Black Bird" on schedule and under budget.

More Than My Share is the personal reflection of Kelly Johnson, edited by Maggie Smith. The seventh of nine children of a stern but not severe Swedish bricklayer who took the wrong train to Nebraska and ended up in Wisconsin, Kelly invented his nickname in grammar school after busting the leg of the school bully who called him "Clara." "Kelly", taken from an Irish fighting song popular at the time, stuck.

"I have known what I wanted to do since I was 12," recalls Kelly. But to get an aeronautical engineering degree at the University of Michigan during the Depression, he had to study civil, chemical, electrical and mechanical engineering -- "an excellent curriculum because it provided a very good basic education in everything it took to design and build an airplane," he recalls. He had only two dates in college and had to feed an ulcer with doughnuts and milk constantly. Unable to find a job after graduation, and with eyesight too poor for the Army Air Corps, Kelly returned to Ann Arbor for graduate study in aerodynamics until he was hired by Lockheed for $83 a month in 1933.

During that time Kelly proved his aeronautical expertise, and was sought out by Amelia Earhart, Howard Hughes, and the Lindbergs. With Anne Lindberg's approval, he fashioned his guiding principles of life: belief in God, good health, purpose in life, a spouse who loves and understands you, and respect for superiors and subordinates.

Ten years later, Kelly promised the Army Air Corps that Lockheed would build, in 180 days, a match for the jet-powered Messerschmitt 262. But Lockheed was booked up, already running three shifts six days a week for the war effort. Kelly, given a free rein, "stole" 22 trusted Lockheed engineers from the main factory, and retrofitted an old machine shop with spares, scrap lumber and a rented circus tent. The YP-80A, the nation's first tactical jet fighter, also the first to break 500 mph, was accepted by the Air Corps 143 days later. His secret, ragtag, makeshift, independent operation was known as "Skunk Works", reminiscent of Li'l Abner's kickapoo joy juice, a hasty brew that included skunks.

Chapter 16, "It's No Secret," is chock full of management techniques used in the dozen or so "Skunk Works" operations Kelly conducted. Early on at Lockheed he learned two lessons from chief engineer Hale Hibbard which contributed to the success of "Skunk Works": excellent labor relations, and "it is much better to lead people, not to drive them." He also believed that those who design aircraft should also fly them, and Kelly insisted on inviting employee families to aircraft christenings. He carried quarters around with him for anyone who could prove him wrong on anything.

Throughout the years, Kelly's first two wives suffered and died. Recently he was funding a hospice at a Burbank hospital for family members, and because "life is too short," he married Nancy Johnson. "The final chapter of my life is not yet written," Kelly concludes. "But if God should call me tonight, I will have had more than my share of it..."

Engineering Management, by David I. Cleland and Dundar F. Kocaoglu, 1981. McGraw-Hill, New York.

Believing "the time has come" for engineering management to be recognized as a distinct discipline, the two founders of the U. of Pittsburgh's engineering management program set out to define, describe and explain what engineers need to know when they become managers. To do this, they concentrate on management theory as applied to engineering, skill in linear programming, and the "values and aspirations" in the attitudes of an engineering manager.

While the 469-page book does not deal with finances nor economics, it does attempt to quantify the subjective values of decision-making. A "hierarchical decision model" in the appendix pulls together much of the probability theory of earlier chapters for use in project planning, evaluation and resource allocations. The book winds down with environmental concerns and legal implications of engineering management.

Cleland had authored a standard textbook earlier, called Systems Analysis and Project Management, and later co-edited the Project Management Handbook (reviewed in NASA SP-6101). Kocaoglu used a systems approach in his 1976 doctoral dissertation at Pitt. Here, however, the emphasis is not on systems analysis but rather upon engineering. The engineer who has little knowledge of management will find more of interest than the manager with little skill in engineering. Using the mathematical models of engineering, the technical specialist is introduced to management responsibilities.

Engineering Management is a bit dated but useful as a graduate-level textbook and as an orientation for engineers who find themselves as managers of projects and people.

The Implementation of Project Management: The Professional's Handbook, edited by Linn C. Struckenbruck, 1987. Addison-Wesley, Reading, Mass.

The Southern California chapter of the Project Management Institute spent two years producing this how-to manual for executives who find themselves in the role of project management. Dr. Linn Struckenbruck, professor of safety and systems management at USC, served as coordinator and provided about half the material in this oversize (9 by 12) handbook.

"This book will discuss the methods and procedures used by successful project managers, and will point out the pitfalls to be avoided in implementing a project," the editor proclaims at the outset. The project manager is an executive who assumes an additional role -- integration -- and becomes ultimately responsible for a large, well-defined but complex project. Hence, the emphasis here is upon the matrix.

Matrix is defined as a dual-authority relationship between the project manager and the functional line manager. The balance of power is in the hands of the former in a tight or strong matrix and with the latter in a weak or loose matrix organization. The ideal is either a balance of power by dividing the responsibilities into overall integration and technical direction, or to shift the balance depending on budget and schedule. In either case, top management support of the matrix concept is fundamental.

More traditional management theories are presented, such as management by objectives (MBO). Fred Peters, chief of programs, scheduling and analysis at Johnson Space Center, co-authors one chapter on MBO in project management. MBO is described as an emphasis on results instead of activities in a goal-oriented project. Yet even the MBO can be incorporated into a matrix when the project manager obtains specific objectives in writing from functional personnel as a way of firming up positive commitments. These concrete objectives then become useful yardsticks in performance evaluation. Pitfalls are listed, but if the objectives are achievable and verifiable, MBO can be a useful tool, for the project manager, even in a matrix organization.

Eight appendices with sample charts add to the value of this handbook. While style and approach vary among the dozen or so writers, with considerable overlap, The Implementation of Project Management is quite readable. Three case histories in the back show applied theory and underscore the lessons learned.

Management: A Bibliography for NASA Managers (NASA SP-7500)

Scientific and Technical Information Division, annual. This bibliography is a collection of references selected from the unclassified reports and journal articles announced in the NASA STI Database. The references are selected based on their timeliness and pertinence to NASA's mission, management and foreign technology exchange. The items are grouped into 10 categories, especially chosen for this bibliography, ranging from Human Factors and Personnel Issues to Management Theory and Techniques. Seven indexes are included: subject, personal author, corporate source, foreign technology, contract number, report number, and accession number. Available from the National Technical Information Service.

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